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A radar system is described for use in vehicular applications. The radar system is particularly suited to backup warning systems and lane-change warning systems. The radar minimizes many of the problems found in the prior art by providing programmable delays and programmable gain. The radar uses a range search algorithm to detect and sort targets at various ranges within the field of view of the radar. Each target range corresponds to a particular delay and gain setting. The radar searches for targets at the various ranges by running a target search algorithm. For each target range, the search algorithm causes the proper time delay and gain setting. Targets within the selected range are detected and catalogued. Speed of the targets is obtained through Doppler processing. A display is used to warn the driver of the vehicle of the presence of targets at the various ranges. The warning may be visual and/or audible. When used in a lane-change system, issuance of an audible warning is based on the speed of the vehicle.

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## HIGH PERFORMANCE VEHICLE RADAR SYSTEM

### Background of the Invention

#### Field of the Invention

5           The present application relates to the field of radar systems for motor vehicles.

#### Description of the Related Art

10           Vehicle safety systems can generally be categorized as either crash protection systems or accident avoidance systems. Crash protection safety systems can minimize the effects of an accident, but an effective accident avoidance system can allow a driver to avoid an accident altogether. This is the basic philosophy that makes automotive radar so attractive as a potential accident avoidance system. Radar systems are particularly suited to backup warning systems that warn the driver that the vehicle is about to back into an object such as a child or another vehicle. Radar systems are also particularly suited to side-object warning systems (also known as blind-spot warning systems) that warn the driver not to change lanes because another vehicle is in the region known as the driver's "blind-spot" or side-object region. The left side-object region is typically slightly behind and to the left of the driver's vehicle. The right side-object region is typically slightly behind and to the right of the driver's vehicle. Many lane-change collisions occur because a driver of a first vehicle desiring to change lanes does not see a second vehicle in an adjacent lane, especially when the front bumper of the second vehicle is beside the rear portion of the first vehicle.

15           Yet, in spite of the obvious desirability, and decades of research, automotive warning radars have not been widely used. To date, automotive radar warning systems have been either too primitive to provide useful information to the driver, or too expensive. Many vehicle radar warning systems in the prior art merely detect the presence of a target, any target, without providing the driver with any information as to the nature or location of the target. One target characteristic of great importance is the distance from the radar to the target (the downrange distance). Many of the simple, inexpensive, radars proposed for automotive use provided no downrange information. Those radars that do provide downrange information typically do not provide accurate downrange information for multiple targets because the radars cannot discriminate between multiple targets. Radars that do attempt to discriminate between multiple targets are generally too costly for most drivers to afford.

25           The simplest automotive radar systems use a Continuous Wave (CW) radar in which a transmitter continuously transmits energy at a single frequency. The transmitted energy is reflected by a target object and received by the radar receiver. The received signal is Doppler shifted by movement of the target object relative to the radar. The CW receiver filters out any returns without a Doppler shift (i.e., targets which are not moving with respect to the radar). When the receiver detects the presence of a Doppler shifted signal, the receiver sends a signal to a warning device that warns the driver. Unfortunately, this type of radar provides no downrange information, and so the driver does not know how close the object is to the vehicle.

Another type of radar found in prior art radar warning systems is a two-frequency CW radar. The two-frequency CW radar transmits energy at a first frequency and a second frequency. The transmitted energy is reflected by a target object and received by a two-frequency CW receiver. The receiver measures the difference between the phase of the signal received at the first frequency and the phase of the signal received at the second frequency. The distance to the target object can be calculated from the measured phase difference. Unfortunately, the two-frequency CW radar performs poorly when there are multiple targets within the field of view of the radar. The simple two frequency system cannot discriminate between two targets at different ranges and thus, the range measurements obtained from a two frequency CW system in the presence of multiple targets is unreliable.

Frequency Modulated Continuous Wave (FMCW) radars have also been used in automotive applications, especially for forward looking systems such as automatic braking and automated cruise control. In an FMCW radar, the frequency of the transmitted signal is swept over time from a starting frequency to an ending frequency. The transmitted signal is reflected by a target and received by the FMCW receiver. The signal received by the receiver is delayed in time according to the travel time of an electromagnetic wave from the transmitter, to the target, and back to the receiver. Since the frequency of the transmitted signal is being varied over time, at any instant in time the frequency of the received signal will be slightly different than the frequency of the transmitted signal. In the absence of Doppler shifting, the distance to the target can be calculated by comparing the frequency of the received signal to the frequency of the transmitted signal. The presence of Doppler shifting will shift the frequency of the received signal and make the target appear to be closer or further away than it actually is.

UltraWideband (UWB) impulse radars have also been proposed for use in vehicle warning systems. However, UWB radars are undesirable because these radars transmit energy over very wide bandwidths and create electromagnetic interference which can interfere with other radio frequency systems such as broadcast radio, television, cellular phones, etc. UWB radars must operate at very low power in order to avoid violating rules promulgated by the Federal Communications Commission (FCC). In addition, UWB radars require antennas that can be used with the very broadband signals transmitted and received by the radar. These very broad band antennas can be difficult to design and build.

Additional problems arise when mounting backup warning radars to large trucks, delivery vans, construction vehicles, and semi-trailers, etc. (collectively "trucks"). Existing backup warning systems and lane-change aids for trucks are expensive and difficult to retrofit into existing truck fleets. Installation of the radar units requires skilled personnel and several hours to install. Existing systems have sensors that must be carefully oriented in order to have the correct field of view. Moreover, signal wires must be run from the radar sensors on the back of the truck to the driver interface in the cab of the truck. For trailers and semi-trailers, these signal wires require the installation of a connector between the tractor and the trailer. This may be especially problematic when the owner of a large fleet of trucks desires to upgrade some or all of the fleet with backup warning radars.



### Summary of the Invention

The present invention solves these and other problems by providing a radar system that can track and discriminate multiple Doppler shifted targets while using a transmitted signal which can be adapted to fit within the radar bands allocated by the FCC. The radar can provide crossrange and downrange information on multiple targets and is not  
5 confused by the presence of Doppler shifting. The radar is simple to build, low in cost, and is well suited to vehicular applications. The radar system is particularly suited to backup warning systems and side-object warning systems in which the driver of a vehicle needs to be warned of an impending collision with an object which is out of the driver's immediate field of view. The present radar minimizes many of the problems found in the prior art by transmitting a pulsed carrier frequency and using a receiver with programmable delays and programmable gain.

10 The receiver uses a range search algorithm to detect and sort targets at various ranges within the field of view of the radar. Each target range corresponds to a particular delay and gain setting. For each target range, the search algorithm sets the proper time delay and gain setting. Targets within the selected range are detected and catalogued. A display is used to warn the operator of the vehicle of the presence of targets at the various ranges. The warning may be visual and/or audible. Crossrange information is obtained by using multiple radar sensors. Each radar sensor detects  
15 targets in a different region around the vehicle. In some embodiments, these regions overlap such that a target may be detected by more than one radar sensor. In one embodiment, the radar is designed to ignore objects, which are stationary with respect to the radar (i.e., targets without Doppler shift). Stationary targets, such as reflections from other parts of the vehicle on which the radar is mounted, usually represent little risk of collision and thus are desirably ignored.

20 The present radar system may be used inside the passenger compartment of a vehicle to detect the presence, size, position, velocity, and/or acceleration of passengers or other objects within the vehicle. Such information can be used, for example, in an intelligent airbag deployment system. The radar may also be used inside the passenger compartment to as part of a throttle position sensing system, which detects the throttle position by detecting the location of a portion of the mechanical throttle linkage, such as, for example, the location of the "gas pedal." In a similar fashion, the radar may also be used to detect the position of the brake pedal, seats, etc.

25 The radar may be used outside the passenger compartment to detect objects behind the vehicle, beside the vehicle, in front of the vehicle, etc. The radar may be used as part of an active suspension system. In one embodiment, the radar may be used to measure the height of the vehicle above the road surface. The radar may also be used to detect the position, velocity, and acceleration of portions of the vehicle suspension system. The radar may also be used to detect anomalies or changes in the road surface. Such anomalies include changes in surface texture, holes (e.g., "pot-holes"), etc.  
30 Information on road surface anomalies may be supplied to the driver, to an active suspension system, etc.

In one embodiment, several intelligent radar sensors are placed in and around the vehicle and each radar sensor is connected to a vehicle information bus. Each radar sensor measures targets within its field of view and broadcasts the radar target information to the vehicle information bus. Other vehicle systems, such as, for example, display units,

suspension units, airbag units, etc. are also connected to the information bus. These other vehicle systems receive the radar target information and use the information to improve the operation, safety, and/or convenience of the vehicle.

The radar sensor may further compute a time to impact based on a downrange distance to a target and a relative velocity between the target and the radar sensor. The radar may provide a field of view that corresponds approximately to the side-object region can be used as both a collision avoidance system and a lane-change aid.

In yet another embodiment, the radar may include an audible warning device configured to project an audible warning signal which varies according to the downrange distance of the closest target, or the relative velocity between the radar and a target, or the time to impact between the radar and a target.

Yet another embodiment of the present invention is an intelligent display for providing information to a driver of a vehicle. The intelligent display includes a sensory display, such as an audible or visual display, and a control processor. The control processor is configured to receive sensor information from a vehicle information bus. The sensor information includes data measured by one or more sensors, such as radar sensors, connected to the information bus. The control processor prioritizes the sensor information and formats the sensory display based on the sensor information.

In yet another embodiment of the present invention, the radar sensor may be integrated into a standard taillight housing assembly for a truck or trailer. Integrating the radar into the taillight housing greatly simplifies the mounting and maintenance problems associated with adding a backup warning system to trucks. The radar sensors for a backup warning system, and/or radar sensors for a lane-change aid may be integrated into one or more of the taillights. In some embodiments, a backup warning radar sensor in the integrated radar-taillight assembly draws power from the power supplied to the reverse light. In another embodiment, the radar sensor in a lane-change aid draws power from the power supplied to a signal light.

In some embodiments, the radar sensor in the integrated radar-taillight assembly communicates with a central control unit by using current-carrier networking. In current carrier networking, the data is modulated onto an alternating current carrier, which is then coupled onto the standard 12 volt or 24 volt direct current (DC) wiring found in the truck. In this manner, the integrated radar-taillight assembly can easily be installed on a trailer or semi-trailer in only a few moments time, by a relatively unskilled worker. Moreover, since the current-carrier network uses the existing wiring, a communication link between the radar sensor and a central control unit is easily provided without extensive modifications or additional wiring in the truck or trailer. A control unit in the cab (or tractor) couples to the taillight wiring in order to communicate with the radar sensor in the remote radar-taillight assembly. The control unit can coordinate the operation of several radar-taillight assemblies and operate an audio-visual display for the driver.

The integrated radar-taillight assembly does not require special purpose mounting, but rather, can use the existing taillight mounting locations. The existing mounting locations are usually provided in relatively protected locations and are available on virtually all trucks. Moreover, the mounting locations are desirably wired for power to service the existing taillights. Hiding the radar sensor in the taillight assembly also helps to prevent theft and vandalism.

Tractors are often used with multiple trailers. Thus, in some embodiments, the driver interface in the cab provides different types of data depending upon the type of sensor installed in the trailer. For example, the maximum downrange distance or the boundaries of the range gates may desirably be different in a trailer that is typically backed up to a dock as compared to a trailer that typically is unloaded at a ramp.

5 The current-carrier network provides a single control unit interface to one or more radar sensors. Many types of sensors may transmit display commands to the driver interface. For example, a tractor may be connected to a trailer having only a backup warning system, a tractor having only a lane-change aid system, or a trailer having both. In each case, the central control unit and the user display in the cab will adapt to, and show data based on, the available sensors.

10 An optical sensor or a current sensor may be provided in the integrated radar-tailight assembly to warn the driver that one or more of the taillights have failed (e.g., burned out).

In yet another embodiment, the radar-tailight assembly uses an array of Light Emitting Diodes (LEDs) in lieu of the more traditional incandescent bulb for the taillights. The LEDs are more reliable, longer lived, provide lower operating temperature, and are more compact than incandescent lamps. An array of LEDs provides considerable fault tolerance, since the failure of a few LEDs in an array will not seriously affect the amount of light produced by the array.

15 In one embodiment, manufacturability and stability of the radar system are improved by replacing analog processing with digital processing. The amount of digital data is reduced by controlling the number of analog-to-digital conversions. Digital samples are produced during desired time periods corresponding to desired target ranges, and digital samples are not produced during other periods corresponding to other target ranges.

20 In one embodiment, the digital samples are produced in by using fast analog sampling followed by lowpass filtering and slow digital sampling. In another embodiment, the digital samples are produced by fast digital sampling and a digital detector in a Digital Signal Processor (DSP). The DSP processes the digital samples (corresponding to a desired target range) in response to a trigger pulse from a time delay. This reduces the amount of data that the DSP will have to process, thereby reducing the complexity and cost of the radar system. In yet another embodiment, an analog-to-digital converter produces digital samples from an intermediate frequency signal in response to a  
25 programmable time delay. The programmable time delay selects samples corresponding to a desired target range (e.g., a desired downrange).

30 Yet another aspect of the invention is a lane-change aid system that detect objects (targets) in a driver's blindspot to help the driver make lane-change maneuvers safer for all and less stressful for the driver. One or more lane-change radars detect targets in side-object regions of the vehicle. The radar sensor allows the lane-change system to distinguish between objects that are relatively close and objects that are relatively far away.

To further reduce false alarms, one embodiment of the lane change aid system uses the speed of the vehicle to determine a maximum target distance for audible alarms. For a given vehicle speed, if a target is detected outside the maximum distance for that given speed, then no audible alarm is issued. Conversely, if a target is detected inside the maximum distance for a given speed, then an audible alarm is issued.

In one embodiment, an alarm is issued when an object is detected on the left side of the vehicle and the left turn signal is activated. Similarly, an alarm is issued when an object is detected on the right side of the vehicle and the right turn signal is activated

5 In one embodiment, a pulsed radar detects a pulse reflected by a target by sensing a trailing edge of the pulse.

In one embodiment, an array of light sources, such as an array of light emitting diodes, is placed in front of a radar antenna. Power supply lines that provide power to the light emitting diodes are oriented to reduce interference between the power supply lines and the radar antenna. In one embodiment, the power supply lines are oriented so that the lines are primarily orthogonal to an E-field produced by the radar antenna.

10 Brief Description of the Figures

The various novel features of the invention are illustrated in the figures listed below and described in the detailed description which follows.

Figure 1A illustrates the operation of a backup warning radar system attached to an automobile.

Figure 1B illustrates a backup warning system attached to a heavy construction vehicle.

15 Figure 2 illustrates the integration of several radar sensors into an automobile.

Figure 3A illustrates a self-contained radar system with integral patch antennas.

Figure 3B illustrates a display panel for use with a radar warning system.

Figure 4 is a block diagram showing the interaction between the RF, analog, and controller sections of the radar system.

20 Figure 5 is a block diagram which illustrates the RF section shown in Figure 4.

Figure 6A is a block diagram of one embodiment of the analog section shown in Figure 4.

Figure 6B is a block diagram of a preferred embodiment of the analog section shown in Figure 4.

Figure 7, comprising Figures 7A and 7B, is a circuit schematic of the RF section corresponding to the block diagram shown in Figure 5.

25 Figure 8, comprising Figures 8A-8D, is a circuit schematic of the analog section corresponding to the block diagram shown in Figure 6B.

Figure 9 is a high level flowchart showing operation of the radar system.

Figure 10 is a flowchart showing the crossrange and downrange target search algorithm.

Figure 11 is a flowchart showing the false target detection algorithm.

30 Figure 12 is a flowchart showing the display update algorithm.

Figure 13, comprising Figures 13A-C, illustrates a truck having several taillight assemblies and a display unit mounted in the cab.

Figure 14, is a block diagram of a backup warning radar system that uses radar sensors integrated into taillight assemblies for reverse lights, brake lights, etc., and that uses the vehicle power system to carry data signals between the radar sensors and the radar control unit.

Figure 15, comprising Figures 15A-G, illustrates various embodiments of a backup warning radar integrated into a taillight assembly.

Figure 16, is a block diagram of a radar sensor that uses carrier-current techniques to communicate with a central control unit.

Figure 17 is a block diagram of a low-cost computer-based radar system that uses a detector based on fast analog sampling followed by lowpass filtering and slow digital sampling.

Figure 18 is a block diagram of a low-cost computer-based radar system that uses a detector based on fast digital sampling and a Digital Signal Processor.

Figure 19A is a block diagram of a low-cost computer-based radar system that uses a detector based on gated fast digital sampling to reduce the number of digital samples.

Figure 19B is a flow chart showing the operation of the digital sampling systems shown in Figures 18 and 19A.

Figure 20 is a block diagram of a lane-change aid system that uses vehicle velocity to reduce the number of false alarms.

Figure 21 is a block diagram of a pulsed radar system that illuminates a target by a pulse of electromagnetic energy.

Figure 22A shows a front view of an array of light emitting diodes with vertical supply lines and horizontal bus lines in front of a radar antenna.

Figure 22B shows a side view of an array of light emitting diodes with vertical supply lines and horizontal bus lines in front of a radar antenna.

Figure 22C shows a front view of an array of light emitting diodes in front of a radar antenna, similar to Figure 22A, except that in Figure 22C, the bus lines are along an outer edge of the array.

In the drawings, the first digit of any three-digit number indicates the number of the figure in which the element first appears. For example, an element with the reference number 404 first appears in Figure 4. Where four-digit reference numbers are used, the first two digits indicate the figure number.

#### Detailed Description of the Preferred Embodiment

Figure 1A illustrates an automobile 100 operating with a backup warning radar system 102. The radar system 102 may be a single radar unit comprising a radar sensor and a control unit. Alternatively, the radar system 102 may be a plurality of radar sensors connected to a common control unit. The radar system 102 may include sensing capabilities for a backup warning system and may also include sensing capabilities for a side-object warning system. The radar system

102 transmits electromagnetic energy (waves) 104, which illuminate targets such as a child 110 and a group 112. The child 110 reflects a wave 108 back to the radar and the group 112 reflects a wave 106 back to the radar. Since the child 110 is closer to the radar 102 than the group 112, the waves 108 reflected from the child 110 will reach the radar 102 before the wave 106 from the group 112 reaches the radar 102. The radar 102 receives the waves 106 and 108 and warns the driver of the automobile 100 that an object is behind the automobile 100. The radar 102 has a field of view, which extends generally behind the vehicle 100. Although the field of view is three dimensional, having a depth, width, and height, since the vehicle moves in two dimensions, it is convenient to talk in terms of a two dimensional field of view. The two dimensional field of view extends some distance behind the vehicle in a downrange direction, and the field of view extends some width behind the vehicle in a crossrange direction. The radar can "see" targets within the field of view defined by the crossrange and downrange limits.

In addition to the field of view, the ability of the radar to see targets is affected by the apparent size of the target. The apparent size of the target is not the actual size, but rather, the size as seen by the radar, measured as a radar cross-section in Decibels per Square Meter (dbsm). The apparent size of an object is often unrelated to the actual size of the object. For example, to the radar 102, the child 110 may appear to be smaller than the group 112. Conversely, the group 112 may appear to be smaller than the child 110. The driver of the automobile 100 should be warned about the child 110 first because the child is closer to the automobile 100 than the group 112. If the driver stops in time to avoid hitting the child 110, then the driver will avoid hitting the group 112 as well. Thus, the radar 102 advantageously warns the driver more strongly about targets that are closer to the radar 102. Targets that are farther from the radar 102 are, at least temporarily, less important and require less of a warning.

Figure 1B is similar to Figure 1A but further illustrates the use of a backup warning radar in a construction or heavy equipment environment. In Figure 1B, the radar 102 is attached to heavy construction vehicle 120. The construction vehicle 120 includes a backup warning device 122 which emits an audible beeping signal whenever the vehicle 120 is backing up. Required warning devices such as the warning device 122 are intended to warn people, such as a worker 124 standing behind the vehicle 120, that the vehicle is backing up. However, experience has shown that in a noisy construction site with many warning devices 122, workers begin to ignore the warning sound and thus accidents involving vehicles backing over workers still occur. Furthermore, the warning device 122 is only effective against people since the driver of the vehicle 120 may still back into an inanimate object. Thus, there is a need for radar warning devices in the construction or heavy equipment environment as well. Such warning devices may provide a different warning external to the vehicle than to the driver.

In either of the situations shown in Figures 1A and 1B, the usefulness of the radar system 102 lies, in part, in the accuracy of the warnings provided. For example, if the radar 102 is so sensitive that it sounds a false alarm every time the vehicle 100 or 120 moves backwards, then the driver of the vehicle will quickly learn to ignore the warning and the effectiveness of the warning is lost. Conversely, if the radar 102 is made so insensitive that it does not sound an alarm in time, then again, the effectiveness of the warning is lost. Many prior art radar systems attempt to control the

number of false alarms by limiting the downrange field of view of the radar. Limiting the downrange field of view is a rather crude solution which denies the driver much of the information needed to avoid a collision in a real-world environment. The present radar system 102 reduces false alarms by providing the driver with additional information, such as downrange and crossrange information, regarding the targets within the field of view of the radar.

5 Figure 2 illustrates the integration of several radar sensors into the automobile 100. The automobile 100 is used in Figure 2 for illustrative purposes only, any vehicle, craft, or structure which could benefit from such radar sensors can be used in place of the automobile 100. Radar sensors 202, 204, and 206 are placed on the rear of the vehicle facing backwards. The sensors 202, 204, and 206 each comprise a radar transmitter and receiver circuit, a transmit antenna, and a receive antenna. The sensor 202 is mounted on the rear center portion of the vehicle and senses targets in a Field of View (FOV) 203 that extends generally directly behind the vehicle. The sensor 204 is placed on the right rear portion of the vehicle and senses targets which are in a FOV 205 that is generally behind the vehicle but to the right of targets sensed by the sensor 202. The sensor 206 is placed on the left rear portion of the vehicle and senses targets which are in a FOV 207 that is generally behind the vehicle but to the left of targets sensed by the sensor 202. The sensor 208 is placed on the right rear of the vehicle and senses targets in a FOV 209 that generally covers the driver's right side-object region. The sensor 210 is placed on the left of the vehicle and senses targets in a FOV 211 that generally covers the driver's left side-object region. The use of five sensors 202, 204, 206, 208, and 210 is preferred, but the use of more or fewer sensors is within the scope of the present invention.

Each of the sensors 202, 204, 206, 208, and 210 is connected to a data bus 220. The data bus 220 is connected to a central control unit 222. The data bus 220 may be dedicated to radar functions. Alternatively, the bus may be a general data bus used by many systems in the vehicle 100. The bus 220 may be a custom bus using non-standard protocols or the bus 220 may use standard protocols, such as, for example, Universal Serial Bus (USB), IEEE-1394 fire wire, ISB, etc. The central control unit 222 monitors, controls the operation of, and gathers data from each of the sensors 202, 204, 206, 208, and 210. The control unit 222 uses data gathered from the sensor to identify targets. A backup switch 226 is connected to the control unit 222 to indicate that the automobile 100 is in reverse. When the automobile 100 is in reverse and a target is identified, then the control unit 222 warns the driver using one or more displays 224.

The control unit 222 may be a control unit dedicated to radar functions or a vehicle control unit which provides general command and control functions for the vehicle 100. In an alternative embodiment, the radar control functions represented by the central control unit 222 are built into each of the sensors 202, 204, 206, 208, and 210 such that each sensor may function as a relatively autonomous sensor that detects targets within its field of view and provides target information to the bus 220 for use by other systems in the vehicle 100.

In one embodiment the displays 224 are provided in areas of the vehicle where a driver will naturally be looking while the vehicle is in reverse. Such areas include areas near rear view mirrors, and near the back of the passenger compartment. Most vehicles are equipped with left and right outside rear-view mirrors, and an inside rear view mirror

which is usually mounted near the top and center of the front windshield. Thus, in a preferred embodiment, a first display 224 is provided near the left outside rear-view mirror, a second display 224 is provided near the right outside rear-view mirror, and a third display 224 is provided near the inside rear view mirror. A display 224 may also be provided near the center of the rear window of the vehicle, either at the top of the window, at the bottom of the window, or both.

5 The displays 224 may be connected to the bus 220 as shown in Figure 2. In one embodiment, the control unit 222 sends commands directly to each display unit 224 that control the operation of the control unit.

In an alternative embodiment, the display units 224 are not controlled by direct commands from the control unit 222, but rather, act as intelligent, relatively autonomous, display devices that monitor the information on the bus 220 and display information based on decisions made within the control 224. For example, the control unit 222 may broadcast  
10 general target information not directed to any particular control unit (e.g., "target at 3 meters") and a control unit 224 connected to the bus 220 may receive the target information and produce a warning display for the driver. Using this embodiment, the number of displays 224, as well as the type of display (e.g., audio, visual, etc.) and the manner in which the information is displayed can be changed without changing the control unit 222.

In a particularly modular embodiment: the radar sensors 202, 204, 206, 208, and 210 are intelligent sensors,  
15 each comprising an internal control unit and each broadcasting target information on the bus 220; and the sensors 224 are intelligent display devices that monitor the information on the bus 220 and display information based on decisions made within the display unit 224. The intelligent sensors may operate in a relatively autonomous mode, or the intelligent sensors may operate in a cooperative mode where one or more of the intelligent sensors communicate with each other. In one cooperative mode, the intelligent sensors operate in a master-slave configuration where one intelligent sensor operates  
20 as the master and the other intelligent sensors operate as the slaves.

Alternatively, the displays 224 may be connected directly to the control unit 222, rather than the bus 220, and are controlled by the control unit 222.

The display 224 may also be provided outside of the vehicle to warn people behind the vehicle. The outside display 224 may be audio, visual, or both and may be provided in combination with the warning device 122 or in lieu of the  
25 device 122. The outside display preferably provides a distinct sound which changes as the vehicle approaches the person 124. Thus, a person 124 standing behind a vehicle 120 hears one sound when the vehicle 120 is far away, or moving slowly, and thus posing little risk to the person 124. The person 124 hears a different sound when the vehicle 120 is close, or moving rapidly towards the person 124 and thus posing a significant risk to the person 124.

Figure 2 illustrates one embodiment of a system for connecting multiple sensors to a control unit 222 wherein  
30 the sensors and the control unit 222 are connected to a common bus 220. The bus 220 may comprise wires, optical fibers, or both. The bus 220 may carry only data for the radar sensors or the bus 220 may be a more general purpose vehicle bus which carries data to and from other vehicle systems. Connecting the radar sensors and/or the controller 222 to a general purpose vehicle bus allows greater interaction between the radar system and other systems in the vehicle,



such as, for example, an automatic braking system, an airbag system, a display system, etc. In another embodiment, each sensor (such as the sensor 202, 204, 206, 208, or 210) is connected to the control unit 222 by a separate cable.

Figure 2 also shows a radar sensor 230 inside the passenger compartment. The radar sensor 230 is connected to a control unit 228 that controls an airbag 232. The radar sensor 230 provides data about a passenger, such as size and location of the passenger, to the control unit 228 and thus improves the ability of the control unit 228 to deploy the airbag 232 effectively.

Figure 3A illustrates a self-contained radar unit 302 with integral patch antennas, including a transmit antenna 304 and a receive antenna 306. The antennas may include multiple patches configured to desirably shape the antenna radiation pattern. A connector 308 provides power, input signals, and output signals from the unit 302. The radar unit 302 may be a sensor, such as the sensor 202, comprising a transmitter and receiver but no central control system. Alternatively, the radar unit 302 may be a complete radar system, comprising a radar sensor (such as the sensor 202) and a control unit such as the control unit 222. In a preferred embodiment, the antennas 304 and 306 are printed circuit patch antennas, but other antennas may be used.

Figure 3B illustrates a display panel 224 for use with the present radar warning system and includes light emitting diodes 312-315 and an audible warning device 320. The diodes 312-315 are used to indicate how close a target is to the automobile 100. In one embodiment, the diode 312 corresponds to the closest targets and the diode 315 corresponds to the most distant targets. In a preferred embodiment, all of the diodes 312-315 are illuminated when a close target is detected and only one of the diodes is illuminated when the only target detected is a distant target. In an alternative embodiment, the number of diodes illuminated is determined by the relative velocity of the target to the radar. In yet another embodiment, the number of diodes illuminated is determined by the time to impact between the target and the radar, a shorter time to impact causing more diodes to be illuminated. In one embodiment, the audible warning device 320 sounds a loud warning when a target is detected at a close range, a quiet warning when a target is detected at a medium range, and no warning when a target is detected at a distant range. The audible warning may comprise a spoken warning message according to the detected target size or range.

Figure 4 is a block diagram of the radar system 102 showing the interaction between a Radio Frequency (RF) section 402, an analog section 404, and a controller section 406. In a preferred embodiment, the RF section 402 and the analog section 404 together comprise a radar sensor, such as the radar sensors 202, 204, 206, 208, 210, and 230 shown in Figure 2. For convenience, only one RF section 402 and analog section 404 are shown in Figure 4, with the understanding that multiple RF sections 402 and multiple analog sections 404 may be connected to a control section 406. The control section (controller) 406 preferably provides the control functions indicated by the controllers 222 and 228 in Figure 2. In a preferred embodiment, the control section 406 comprises a microprocessor-based controller with an Analog to Digital Converter (ADC) for converting the analog signal 420 into a digital format. In an alternative embodiment, the ADC may be moved to the analog section 404 so that radar target data is passed from the analog section 404 to the controller section 406 in digital form. The ADC is preferably a 12-bit converter.

The RF section 402 provides a transmitter output signal to the transmit antenna 304. The receive antenna 306 provides received signals to the RF section 402. The analog section 404 provides a transmit timing signal 410 and a receive timing signal 412 to the RF section 402. The RF section 402 provides an Intermediate Frequency (IF) signal 414 to the analog section 404. The IF signal 414 comprises signals which have been received by the RF section 402 and downconverted to baseband as explained in more detail below.

As explained in more detail below in the text accompanying Figures 5 and 6, a pulse on the transmit timing signal 410 causes the RF section to send an RF transmit pulse to the transmit antenna 304. Some time after each transmit pulse, the analog section 404 sends a pulse on the receive timing signal 412 to open a receive window. Since the receive window is only open for a specified period of time, only targets within that time period are seen by the radar. The target time can easily be converted to distance because the timing of a received wave from a particular target is a function of the travel time for the electromagnetic wave from the transmit antenna to the target and back to the receive antenna. The travel time for an electromagnetic wave in air is approximately 1 nanosecond (ns) per foot. Thus, the receiver time window for a target 1 foot away from the transmit and receive antennas is approximately 2 ns after the transmit pulse. When the receive window opens, the RF section 402 sends IF data on the IF signal 414 to the analog section 404.

The analog section 404 provides further signal processing on the IF signal 414 to produce an analog radar signal 420. The analog section 404 provides the analog radar signal 420 to the controller section 406. The analog radar signal 420 is the analog output from the radar and includes all target information. The controller 406 uses an analog to digital converter to convert the analog radar signal 420 into the digital domain for further target processing.

The controller 406 provides a sensor enable signal 421, a program enable signal 422, a program clock 424, and a program data in signal 426 to the analog section 404. When asserted, the sensor enable signal 421 causes the radar analog section 404 to start sending the transmit timing signal 410 to the RF section 402. The program enable signal 422, the program clock 424, and the program data in signal 426 are used by the controller to program and configure portions of the analog section 404, including a programmable delay line and a two stage programmable gain amplifier described in connection with Figure 6.

Figure 5 is a block diagram of the RF section 402. A carrier frequency oscillator 502 in the RF section 402 provides an RF signal to an input of a power divider 504. In a preferred embodiment, the oscillator 502 provides a 5.8 GHz signal. A first output of the power divider 504 is provided to an input of an RF amplifier 506. An output of the RF amplifier 506 is provided to one terminal of a Single Pole Single Throw (SPST) switch 508. A second terminal of the SPST switch 508 is provided to the transmit antenna 304. The SPST switch 508 is a high frequency switch which can be switched on and off in nanosecond timeframes. The SPST switch 508 is also configured to pass the RF signal at 5.8 GHz without significant attenuation.

The transmit signal 410 is provided to a pulse generator 510 which provides a fixed width pulse to a control input of the SPST switch 508. The SPST switch 508 is normally in an open position. The pulse provided by the pulse generator 510 closes the SPST switch 508 for a fixed time interval and then re-opens the SPST switch 508 until the next

transmit pulse. During the time interval when the SPST switch 508 is closed, the unmodulated 5.8 GHz carrier at the output of the RF amplifier 506 is provided to the transmit antenna 304 and a short burst of RF energy is transmitted by the antenna. In a preferred embodiment, the SPST switch 508 is closed for 10 nanoseconds. Thus, in the preferred embodiment, the bandwidth of the transmitted pulse is approximately 200 MHz or approximately 3% of the carrier 5.8 GHz frequency.

A second output of the power divider 512 is provided to an input of an RF amplifier 512. An output of the RF amplifier 512 is provided to a Local Oscillator (LO) input of a mixer 514. An output of the receive antenna 306 is provided to an input of an RF Low Noise Amplifier (LNA) 516 and an output of the amplifier 516 is provided to an RF input of the mixer 514. An output of the mixer 514 is provided to an input of a lowpass filter 518. An output of the lowpass filter 518 is fed through a Direct Current (DC) block 520 to an input of an IF amplifier 522.

Energy transmitted by the transmit antenna 304 is reflected by targets within the FOV and is received by the receiving antenna 306. If the target is stationary with respect to the antennas 304, 306, then the received energy will have the same frequency as the transmitted energy (5.8 GHz). If the target is not stationary with respect to the antennas 304, 306, then the received energy will, due to the Doppler effect, be shifted in frequency. The frequency shift is approximately 25 Hz/mile/hour. The mixer 514, lowpass filter 518, and DC-block 520 downconvert and filter the received signal from RF frequencies to IF (audio) frequencies. Received energy which is not Doppler shifted will appear at the output of the mixer 514 as DC and will be blocked by the DC-block 520. Received energy which is Doppler shifted will appear at the output of the mixer 514 at the baseband Doppler shift frequency. Thus, a target moving at 2 miles/hour with respect to the antennas will produce a signal of approximately 50 Hz at the output of the IF amplifier 522.

An output of the IF amplifier 522 is provided to a first terminal of a SPST switch 524. A second terminal of the SPST switch 524 is the IF signal 414. The receive timing signal is provided to an input of a pulse generator 526 and an output of the pulse generator 526 is provided to a control input of the SPST switch 524.

Like the SPST switch 508, the SPST switch 524 is normally in an open position. The pulse provided by the pulse generator 526 closes the SPST switch 524 for a fixed time interval and then re-opens the SPST switch 524 until the next receive timing pulse occurs on the receive timing pulse signal 412. During the time interval when the SPST switch 524 is closed, the IF signal at the output of the IF amplifier 522 is provided to the IF signal path 414. In a preferred embodiment, the SPST switch 524 is closed for 5 nanoseconds.

Figure 6A is a block diagram of one embodiment of the analog section 404. The embodiment shown in Figure 6A advantageously operates without the use of a separate controller section 406, but it is limited to a preset number of range outputs. In Figure 6A, an output of a pulse repetition frequency (PRF) generator 602 is provided to the transmit timing signal 410, to an input of a selectable time delay 604, and to a clock input of a programmed counter 612. In a preferred embodiment, the PRF generator operates at a frequency of 5.7 MHz.

Each of four time delay outputs of the time delay 604 are provided to a separate throw of a Single Pole Four Throw (SP4T) switch 605. The fourth (longest) time delay output of the time delay 604 is also provided to an input of a

time delay 606. Each of four time delay outputs of the time delay 606 are provided to a separate throw of a SP4T switch 607. The fourth (longest) time delay output of the time delay 606 is also provided to an input of a time delay 608. Each of four time delay outputs of the time delay 608 are provided to a separate throw of a SP4T switch 609. The fourth (longest) time delay output of the time delay 608 is also provided to an input of a time delay 610. Each of four time delay  
 5 outputs of the time delay 601 are provided to a separate throw of a SP4T switch 611. The poles of each of the SP4T switches 605, 607, 609, and 611 are each provided to a separate throw of a SP4T switch 614. The pole of the switch 614 is the receive timing signal 412.

Two of the output bits of the counter 612 are provided to a control input of the SP4T switch 614 and to a control input of a SP4T switch 616. The IF signal 414 is provided to the pole of the SP4T switch 616. Each throw of the  
 10 SP4T switch 616 is connected to an input of separate IF amplifier (amplifiers 620, 622, 624 and 626). An output of the IF amplifier 620 is connected to an input of a bandpass filter 630. An output of the IF amplifier 622 is connected to an input of a bandpass filter 632. An output of the IF amplifier 624 is connected to an input of a bandpass filter 634. An output of the IF amplifier 626 is connected to an input of a bandpass filter 636. The outputs of the bandpass filters 630, 632, 634, and 636 are analog target outputs, each output corresponding to a different downrange distance.

The counter 612 operates the SP4T switches 614 and 616 in unison such that each time delay selected by the SP4T switch 614 corresponds to a range output of the bandpass filters 630, 632, 634, and 636. In a preferred embodiment, the counter 612 moves the switches 614 and 616 to a new pole every 128th transmit pulse on the transmit timing signal 410. In other words, the switches 614 and 616 dwell on each range gate for 128 transmit pulses. The  
 15 bandpass filters 630, 632, 634, and 636 operate like integrators to average the signal received from the 128 transmit pulses and thus smooth the output signals. The switches 604, 606, 608 and 610 are preset to provide a desired set of four delay times corresponding to four downrange distances. In a preferred embodiment, the four delay times are 1 nanosecond (ns), 8 ns, 13 ns, and 20 ns, corresponding to downrange distances of .5 ft, 4ft, 6.5 ft, and 10 ft.

Figure 6B is a block diagram of a preferred embodiment of the analog section 404 which provides programmable delays (range gates) and programmable gains in the IF amplifiers for any number of downrange distances. In a preferred  
 25 embodiment, the downrange distances are from approximately 0-60 ft. In Figure 6B, an output of the PRF generator 602 is provided to a first terminal of a SPST transmit enable switch 644 and to a clock input of a timing generator 643. The sensor enable signal 421 is provided to an enable input of the timing generator 643. A control output of the timing generator 643 is provided to a control input of the transmit enable switch 644.

A second terminal of the transmit enable switch 644 is provided to the transmit timing signal 410 and to an  
 30 input of a programmable delay 646. The programmable delay 646 is programmed by inputs provided by the program enable signal 421, the program clock signal 424, and the program data in signal 426. In a preferred embodiment, the programmable delay 646 can generate time delays from 0-118 ns, in .5 ns intervals, corresponding to downrange distances of approximately 0-59 ft.

The IF signal 414 is provided to an input of a lowpass filter 648. An output of the lowpass filter 648 is provided to an input of a DC-block 650. An output of the DC-block 650 is provided to an input of a first programmable gain amplifier 652 and to a first terminal of a SPST switch 660. The program enable signal 421 is provided through a 5 ms (millisecond) delay to a control input of the switch 660. A second terminal of the SPST switch 660 is connected to ground.

An output of the first programmable gain amplifier 652 is provided to an input of a second programmable gain amplifier 654. An output of the second programmable gain amplifier is provided to an input of a lowpass filter 656. An output of the lowpass filter 656 is the analog output signal 420. The first and second programmable amplifiers 652 and 654 are programmed by inputs provided by the program enable signal 421, the program clock signal 424, and the program data in signal 426.

In a preferred embodiment, the lowpass filter 648 has a rolloff frequency of approximately 500 Hz at a rate of 15 dB/decade and the lowpass filter 656 has a rolloff frequency of approximately 500 Hz at a rate of 15 dB/decade. The voltage gain of the first programmable gain amplifier 652 is preferably adjustable from 1 to 252 and the voltage gain of the second programmable gain amplifier 654 is preferably adjustable from 8 to 38.

Figure 7 is a circuit schematic of an RF section corresponding to the block diagram shown in Figure 5. The carrier frequency oscillator 502 is based on a 5.8 GHz oscillator 702. A 7 volt supply is provided to a Vcc input of the oscillator 702, and the 7 volt supply is bypassed to ground at the oscillator by a capacitor 706 and a capacitor 707. The 7 volt supply is also provided to a first terminal of a resistor 703. A second terminal of the resistor 703 is connected to a first terminal of a resistor 704, to a first terminal of a capacitor 705, and to a bias terminal of the oscillator 702. An output of the oscillator 702 is the output of the carrier frequency oscillator block 502. In a preferred embodiment, the capacitor 706 is a 33 uF (microfarad) capacitor, the capacitor 707 is a 1 uF capacitor, the capacitor 705 is a 33 pF (picofarad) capacitor, the resistor 703 is an 11 k $\Omega$  resistor, the resistor 704 is a 39 k $\Omega$  resistor, and the oscillator 702 is a Voltage Controlled Oscillator (VCO) manufactured by MODCO.

The output of the oscillator 702 is provided to a first terminal of a resistive matching network 710. A second terminal of the resistive matching network 710 is connected to an input of the power divider 504. In a preferred embodiment, the power divider 504 is a single stage Wilkinson power divider with a resistor 711 of 100  $\Omega$ . An output of the power divider 502 is provided through a DC-blocking capacitor 712 to an input of the amplifier 506. An output of the amplifier 506 is connected to the 7 volt supply by a resistor 714, to ground by a capacitor 715, and through a DC-blocking capacitor 716 to a first terminal of a matching network 720. The switch 508 comprises a solid state switch 721. A second terminal of the matching network 720 is connected through a DC-blocking capacitor 713 to a first terminal of the solid state switch 721. A second terminal of the solid state switch 721 is connected through a DC-blocking capacitor 722 to a first terminal of a matching network 723. A second terminal of the matching network 723 is connected to the transmit antenna 304.

In a preferred embodiment, the impedance matching networks 710, 720, and 723 are PI network attenuators with an attenuation range of 0 dB - 10 dB. The DC-blocking capacitors 712, 716, 713, and 722 are 33 pF capacitors. The resistor 714 is a 64  $\Omega$  resistor and the capacitor 715 is a 33 pF capacitor. The solid state switch is preferably an ASD06M1-16 supplied by Alpha.

5       The pulse generator 510 comprises a delay line 739. The transmit timing signal 410 is provided through a resistor 740 to a data input of the delay line 739. A 5 volt supply voltage is provided to a Vcc input, a P0 input, and a P1 input of the delay line 739. A ground is provided to a P2 input and a ground input of the delay line 739. In a preferred embodiment, the delay line 739 is a DS1040 from Dallas Semiconductor Corp.

10       An output of the delay line 739 is provided through a DC-blocking capacitor 738 to a first terminal of a resistor 736, to a first terminal of a resistor 737, and to a first input of an xor (exclusive-or) gate 733. A -5.0 volt supply voltage is provided to a second terminal of the resistor 737, to a second input of the xor gate 733, and to a first input of an xor gate 730. An output of the xor gate 733 is provided to a second input of the xor gate 730. An output of the xor gate 730 is provided through a resistor 726 to a V2 control input of the solid state switch 721. The output of the xor gate 730 is also connected to ground by a resistor 728. A bias input of the xor gate 730 is connected to the cathode of a diode 732 and the anode of the diode 732 is connected to ground.

15       A second terminal of the resistor 736 is connected to a first input of an xor gate 731. A second input of the xor gate 736 is connected to ground and a bias input of the xor gate 736 is connected to ground. An output of the xor gate 731 is provided through a resistor 727 to a V1 control input of the solid state switch 721. The output of the xor gate 731 is also connected to ground by a resistor 729.

20       In a preferred embodiment, the resistors 737, 728, and 729 are 1 k $\Omega$  resistors, the resistor 736 is a 0  $\Omega$  resistor, the resistors 726 and 727 are 10  $\Omega$  resistors, and the diode 732 is replaced by a 0  $\Omega$  resistor. The xor gates 730, 731, and 733 are preferably 74AC86 types.

25       A second output of the power divider 504 is provided through a DC-blocking capacitor 742 to an amplifier 512. An output of the amplifier 512 is provided to the 7 volt supply by a resistor 744, to ground by a capacitor 745, and through a DC-blocking capacitor 746 to a first terminal of a matching network 747. A second terminal of the matching network 747 is provided to the LO input of the mixer 514.

      The output of the receive antenna 306 is provided through a DC-blocking capacitor 750 to an input of the amplifier 515. An output of the amplifier 516 is provided to the 7 volt supply by a resistor 751, to ground by a capacitor 752, and through a DC-blocking capacitor 753 to the RF input of the mixer 514.

30       In a preferred embodiment, the capacitors 750, 751, and 752 are 33 pF capacitors, and the resistor 751 is a 220  $\Omega$  resistor. The amplifier 516 is preferably an MGA-86363 2-8 GHz amplifier supplied by Hewlett-Packard and the mixer 514 is an HMC168C8 supplied by Hitite.

The output of the mixer 514 is provided to a first terminal of an inductor 755. A second terminal of the inductor 755 is connected to ground through a capacitor 756 and to a first terminal of an inductor 757. A second terminal of the inductor 757 is connected through the DC-blocking capacitor 520 to an input of an amplifier 760. An output of the amplifier 760 is provided to a first terminal of an inductor 761 and to a DC-blocking capacitor 770. A second terminal of the inductor 761 is connected through a resistor 762 to the 7 volt supply.

In a preferred embodiment, the inductors 755 and 757 are 90 nH inductors, the capacitor 756 is a 3 pF capacitor, and the DC-blocking capacitor 520 is a 1 uF capacitor. The amplifier 760 is preferably a VAM-6 supplied by Mini-Circuits. The inductor 761 is a 47 nH inductor and the resistor 762 is a 220  $\Omega$  resistor.

The output of the amplifier 760 is also connected through a DC-blocking capacitor 770 to an input of an amplifier 772. An output of the amplifier 772 is provided to a first terminal of an inductor 773 and to a DC-blocking capacitor 776. A second terminal of the inductor 773 is connected through a resistor 775 to the 7 volt supply.

The amplifier 772 is preferably a VAM-3 supplied by Mini-Circuits. In a preferred embodiment, the inductor 773 is a 47 nH inductor and the resistor 775 is a 65  $\Omega$  resistor.

The switch 524 comprises a solid state switch 777. An output of the amplifier 772 is provided through a DC-blocking capacitor 776 to a first terminal of the solid state switch 777 and a second terminal of the solid state switch 777 is provided to the IF signal 414. The second terminal of the solid state switch 777 is also provided to ground through a capacitor 790. The receive timing signal 412 is provided through a resistor 526 to a data input terminal of a delay line 785. The 5 volt supply is provided to a Vcc input and to a P0 input of the delay line 785. The ground is provided to a P1 input, to a P2 input, and to a ground input of the delay line 785. An output data terminal of the delay line 785 is provided to a first input of an xor gate 782 and to a first input of an xor gate 783. A second input of the xor gate 782 is provided to ground, and a second input of the xor gate 783 is provided to the 5 volt supply. An output of the xor gate 782 is provided through a capacitor 781 to a first control input of the solid state switch 777. An output of the xor gate 783 is provided through a capacitor 780 to a second control input of the solid state switch 777. The 5 volt supply is also provided through a resistor 778 to the first control input of the solid state switch 777. A ground is also provided through a resistor 779 to the second control input of the solid state switch 777.

In a preferred embodiment, the resistor 784 is a 0  $\Omega$  resistor, the resistors 778 and 779 are 1 k $\Omega$  resistors, and the capacitors 781, 780, and 790 are 1000 pF capacitors. The delay line 785 is preferably a DS1040, the solid state switch 777 is an SW239 switch supplied by M/A Com, and the xor gates 782 and 783 are 74AC86 types.

Figure 8 is a circuit schematic of an analog section 404 corresponding to the block diagram shown in Figure 6B. Figure 8 shows the PRF generator 642 comprising an inverter 807, an inverter 806, and an inverter 804. An output of the inverter 807 is provided to a first terminal of a resistor 803 and to an input of the inverter 806. An output of the inverter 806 is provided to a first terminal of a capacitor 808 and to an input of the inverter 804. A second terminal of the

capacitor 808 is provided to a second terminal of the resistor 803 and to a first terminal of a resistor 809. A second terminal of the resistor 809 is provided to an input of the inverter 807.

In a preferred embodiment, the resistor 809 is a 620  $\Omega$  resistor, the resistor 803 is a 62  $\Omega$  resistor, and the capacitor 808 is a 1000 pF capacitor.

5 An output of the inverter 804 is provided to a first terminal of a pull-up resistor 805, to a first input of a nand gate 810, and to a clock input of a first counter 817. A VDD input of the first counter 817 is connected to a 5 volt supply voltage Vcc. An RST and a VSS input of the first counter 817 are connected to ground. A Q1 output of the counter 817 is provided to a clock input of a second counter 816 and to a clock input of a programmable array logic device (PAL) 815. A VDD input of the second counter 816 is connected to a 5 volt supply voltage Vcc and a VSS input of the second counter 10 817 is connected to ground. Outputs Q5-Q8 of the second counter 816 are provided to inputs I1-I4, respectively, of the PAL 815. The program clock signal 424 is provided to an input I5 of the PAL 815, the program enable signal 422 is provided to an input I7 of the PAL 815, and the sensor enable signal 421 is provided to an input I10 of the PAL 815. A transmit enable output (on pin IO-5) of the PAL 815 is provided a second input of the nand gate 810 and a reset output (on pin IO-9) of the PAL 815 is provided to a reset input of the second counter 816.

15 In a preferred embodiment, the first and second counters 817 and 816 are 14040 12-bit counters supplied by National and the PAL 815 is a PAL22V10-PLCC supplied by Lattice. The PAL 815 is programmed according to a PAL source program given in Table 1.

An output of the nand gate 644 is provided to a pull-up resistor 811, to a data input of a fixed time delay 812, and to a data input of programmable time delay 813. A COM signal on the fixed time delay 812 is provided to ground and 20 a 10ns delay output of the fixed delay 813 is provided to the transmit timing signal 410. Outputs P1-P7 of the programmable time delay 813 are connected together and pulled up to Vcc by a pull-up resistor 814. A MOD input of the programmable delay 813 is provided to ground. The program enable signal 422 is provided to a program enable input of the delay 813. The program clock signal 424 is provided to a program clock input of the delay 813. The program enable data in 426 is provided to a program data input of the delay 813.

25 In a preferred embodiment, the pull-up resistors 811 and 814 are each 1 k $\Omega$  resistors. The fixed delay 812 is preferably a SIL2T-10ns supplied by Rhombus and the programmable delay 813 is a DS1021-50 supplied by Dallas Semiconductor.

The delay 813 is a programmable 8-bit silicon delay line. Delay values can be varied over 256 equal steps with an incremental delay of 0.5 ns. The output of the delay 813 will substantially reproduce the logic state of the input after a 30 delay time determined by an 8-bit value clocked into the data input of the delay 813. When the program enable signal 422 is at a logic high, timing data is loaded in MSB (most significant bit) to LSB (least significant bit) order by the rising edge of the program clock signal 424. As timing values are shifted into the program data input of the delay 813, the previous contents of the 8-bit input are shifted out of the program data output in MSB-to-LSB order.



The program enable signal 422 is provided through a series resistor 821 to the base of a transistor 823. The emitter of the transistor 823 is provided to ground. The collector of the transistor 823 is connected to Vcc by a resistor 422, to first and second inputs of a 2-input nand gate 825 and to ground by a capacitor 824. An output of the nand gate 825 is provided to a control input of a SPST switch 660. A second terminal of the SPST switch 660 is connected to ground.

In a preferred embodiment, the resistors 821 and 822 are 4.7 k $\Omega$  resistors, the transistor is a 2N2222, the capacitor 824 is a 1 uF capacitor, the nand gate is a 74AC00, and the SPST switch 660 is a CD4066.

The IF signal 414 is provided to the lowpass filter 648 comprising a resistor 845, a capacitor 846, and a resistor 847. The IF signal 414 is provided to a first terminal of the resistor 845 and the second terminal of the resistor 845 is provided to a first terminal of the capacitor 846, to a first terminal of the resistor 847, and to a first terminal of a DC-blocking capacitor 610. A second terminal of the capacitor 846 and a second terminal of the resistor 847 are both provided to ground. A second terminal of the DC-blocking capacitor 610 is provided to a first terminal of the SPST switch 660, to a first terminal of a resistor 819, and to a first fixed terminal (also called the LO terminal) of a programmable potentiometer 820. A second fixed terminal (also called the HO terminal) of the programmable potentiometer 820 is provided through a series resistor 828 to an output of a first operational amplifier (op-amp) 827. A non-inverting input of the op-amp 827 is provided to ground and an inverting input of the op-amp 827 is provided to a wiper terminal (WO) of the programmable potentiometer 820.

The program enable signal 422 is provided to a program enable input of the potentiometer 820. The program clock signal 424 is provided to a program clock input of the potentiometer 820 and the program enable data in signal 426 is provided to a program data input of the potentiometer 820. A program data output from the delay line 813 is provided to a program data input of the potentiometer 820.

In a preferred embodiment, the resistor 845 is a 100  $\Omega$  resistor, the capacitors 846 and 610 are 1 uF capacitors, the resistors 847 and 819 are 4.7 k $\Omega$  resistors, and the resistor 828 is a 100 k $\Omega$  resistor. The op-amp 827 is preferably an LM2902 supplied by National Semiconductor. The potentiometer 820 is a DS1267-100A (100 k $\Omega$ ) supplied by Dallas Semiconductor. The DS1267-100A is a dual potentiometer, having a first potentiometer 820 with terminals LO, WO, and HO and a second potentiometer 830 with terminals L1, W1, and H1. Each of the dual potentiometers are separately programmable.

The programmable resistor 820 in combination with the op-amp 827 comprise the first programmable gain stage 612. The programmable potentiometer 820 is similar to a mechanical potentiometer with a first fixed terminal (LO) a second fixed terminal (HO) and a wiper (WO). The location of the wiper WO is programmed by asserting the program enable signal 422 and using the program clock 424 to clock data from the program data in signal 426 into a shift register inside the programmable potentiometer 820. The programmable potentiometer 820 is composed of 256 resistive sections. Between each resistive section and both ends of the potentiometer are tap points that are accessible to the wiper. The

position of the wiper on the resistive array is set by an 8-bit value that controls which tap point is connected to the wiper output. The programmable potentiometer 820 is programmed in a manner similar to the programmable delay line 813. By connecting the program data output of the delay 813 to the program data input of the potentiometer 820, multiple devices can be daisy-chained (cascaded) for programming purposes. The programmable potentiometer 820 is programmed by a 17-bit word comprising: an 8-bit value for wiper W0; an 8-bit value for wiper W1; and a 1-bit stack select bit (the stack select bit is not used the preferred embodiment).

The output of the op-amp 827 is provided through a resistor 829 to a wiper (W1) of the programmable potentiometer 830. The potentiometers 820 and 830 are part of a dual unit so the programming lines used to program the potentiometer 820 are also used to program the potentiometer 830. A fixed terminal H1 of the potentiometer 830 is connected to a wiper (W0) of a programmable potentiometer 831.

A program data output from the potentiometer 820 is provided to a program data input of the programmable potentiometer 831. The program enable signal 422 is provided to a program enable input of the potentiometer 831 and the program clock signal 424 is provided to a program clock input of the potentiometer 831. A fixed output (H0) of the potentiometer 831 is provided to an inverting input of a second op-amp 833. A non-inverting input of the second op-amp 833 is provided to ground. A feedback resistor 832 is connected between the inverting input of the second op-amp 833 and to an output of the second op-amp 833. The combination of the second op-amp 833, the programmable potentiometer 830, the programmable potentiometer 831, and the feedback resistor 832 comprises the second programmable gain stage 654.

In a preferred embodiment, the programmable potentiometer 831 is a DS1267, the feedback resistor 832 is a 2 M $\Omega$  (megaohm) resistor, and the second op-amp 833 is an LM2902.

An output of the second op-amp 833 is provided to a first terminal of a resistor 834. A second terminal of the resistor 834 is provided to a first terminal of a capacitor 835, to a first terminal of a resistor 836, and to the analog out signal 420. A second terminal of the capacitor 835 and a second terminal of the resistor 836 are provided to ground. The combination of the capacitor 835 and the resistors 834 and 836 comprises the lowpass filter 656.

In a preferred embodiment, the capacitor 835 is a 1  $\mu$ F capacitor, the resistor 834 is a 100  $\Omega$  resistor, and the resistor 836 is a 4.7 k $\Omega$  resistor.

TABLE 1

PAL Source Program	
1.	MODULE ANALOG3
2.	TITLE 'Analog Board Control Logic'
3.	"AN3CTL device 'p22v10';
4.	"Constants
5.	C,P,X = .c., .p., .x.;
6.	

```

7.  "Inputs
8.  CLK                pin2;
9.  C3,C4,C5,C6       pin 3,4,5,6;
10. BPClk             pin 7;
5  11. RF_Data_        pin 9;
12. Pgm_Enb_          pin 10;
13. "PS0,PS1          pin 11,12;
14. Sns_Enb_          pin 13;
15. Rst_RFD_          pin 16;
10 16.
17. "Outputs
18. "RF_Detect         pin 17 istype 'reg,buffer';
19. "Sns_Act           pin 18 istype 'reg,buffer';
20. "LSns_Go           pin 19 istype 'reg,buffer';
15 21. "LSns_Go1        pin 20 istype 'reg,buffer';
22. Tx_Enb            pin 21 istype 'reg,buffer';
23. "RF_Sample         pin 23 istype 'reg,buffer';
24. LPgm_Enb          pin 24 istype 'reg,buffer';
25. "Hold_1267         pin 25 istype 'reg,buffer';
20 26. "Tmr_Clk         pin 25 istype 'reg,buffer';
27. Rst_Ctr           pin 26 istype 'reg,buffer';
28. Init_Sns_         pin 27 istype 'reg,buffer';
29.
30. "    COUNT.AR = RST;
25 31.
32. "Set Declarations
33.
34. "State Declarations
35.
30 36. equations
37.
38. Init_Sns_.C = CLK;
39. Tx_Enb.C = CLK;
40. Rst_Ctr.C = CLK;
35 41. Hold_1267.C = CLK;
42. LPgm_Enb.C = CLK;
43. !Init_Sns_ := Init_Sns_ & !Init_Sns_;
44. Tx_enb := !Sns_enb_;
45. Rst_Ctr := LPgm_Enb;
40 46. Hold_1267 := LPgm_Enb;
47. # !LPgm_Enb & Hold_1267 & !C6;
48. LPgm_Enb := Pgm_Enb;
49.
50. End

```

Figure 9 is a high level flowchart showing operation of the controller 406. The process shown in the flowchart of Figure 9 begins at an initialization process block 902 where the controller initializes the radar system hardware, data structures, and the controller interrupt structure. Hardware initialization includes initializing the RF section 402, the analog

section 404, and the controller 406. After initialization, the process advances to a decision block 903 where the controller determines whether or not the vehicle 100 is in reverse. If the vehicle is in reverse, then the process advances to a process block 904. If the vehicle is not in reverse then the process re-enters the decision block 903.

In the process block 904, the controller 406 collects radar target data according to the flowchart shown in Figure 10. Upon completion of the process block 904, the process advances to a process block 906 where the controller analyzes the target data according to the flowchart shown in Figure 11. Upon completion of the process block 906, the process advances to a process block 908 where the controller updates the display 224 according to the flowchart shown in Figure 12. Upon completion of the process block 908, the process jumps back to the decision block 903.

As shown in the flowchart of Figure 9, whenever the vehicle is in reverse, the controller 406 continuously collects radar target data from one or more analog sections (such as the analog section 404), analyzes the collected data, and updates the display 224 based on the results of the data analysis.

Figure 10 is a flowchart showing the data collection process which includes a search for targets in both crossrange and downrange directions. The search begins with a loop process block 1002 where a downrange distance D is selected. The process then advances to a loop process block 1006 where a radar sensor S (comprising an analog section 404) is selected. Having selected a downrange distance and a sensor, the process advances to a process block 1008 where a time delay, corresponding to the distance D, is programmed into the programmable time delay 646 in the sensor S. Also in the process block 1008, a desired gain is programmed into the analog section 404. The desired gain is programmed by programming the programmable potentiometers 820, 830, and 831. Once the delay and gain have been programmed, the process advances to a process block 1010 where target data is obtained. Target data is obtained by asserting the sensor enable signal 421 and then sampling target data (using the ADC) on the analog signal line 420. In a preferred embodiment, three samples are obtained.

The sampled target data (e.g., three samples) are passed to a process block 1012 where a peak target voltage Vp is estimated. In general, the analog signal 420 exhibits an oscillatory behavior that approximates a sine wave for time periods of a few cycles. An estimate of the peak value Vp of the analog signal 420 is obtained from the data obtained in the process block 1010. In a preferred embodiment, the estimate of the peak value is obtained by selecting the largest sample obtained in the process block 1010. Thus, in a preferred embodiment,  $V_p = \max(S_1, \dots, S_N)$  where  $S_1$  is the first sample,  $S_N$  is the last sample, and  $N=3$ . In an alternative embodiment, the value of Vp is obtained by parameter estimation of a sine wave using three samples  $S_1$ ,  $S_2$  and  $S_3$  at times  $t_1$ ,  $t_2$  and  $t_3$  respectively. The amplitude A of the estimated sine wave may be calculated by the equation

$$A = \sqrt{S_2 + \dot{S}_2^2 S_2 / \ddot{S}_2}$$

where

$$\dot{S}_2 = \frac{S_3 - S_1}{t_3 - t_1}$$

and

$$\tilde{S}_2 = - \frac{\frac{S_2 - S_1}{\Delta t} - \frac{S_3 - S_2}{\Delta t}}{\Delta t}$$

where  $\Delta t = t_3 - t_2 = t_2 - t_1$ . The frequency of the estimated sine wave can be calculated by the equation  $\omega = \sqrt{\tilde{S}_2 / S_2}$ . The estimated relative target velocity with respect to the radar is proportional to the frequency of the estimated sine wave and thus target velocity can be computed from the estimated frequency. The relative target acceleration with respect to the radar may be computed by using two successive estimates of the estimated velocity.

Once the value of  $V_p$  has been determined in the process block 1012, the process advances to a process block 1014 where  $V_p$  is stored in a database for later use by the data analysis process shown in Figure 11. The process then advances to a loop test block 1016, which selects the next sensor. When the sensor loop, comprising the process blocks 1006 and 1016 has looped through all sensors, then the process advances to a loop test block 1018 which selects the next downrange distance. The process is complete when the downrange loop, comprising the process blocks 1002 and 1018, has looped through all of the downrange distances.

Figure 11 is a flowchart showing the data analysis process, which includes a false target detection algorithm. The database generated by the flowchart of Figure 10 comprises a set of values  $V_p(r,s,k)$ , where  $r$  is an index which selects the downrange distances,  $s$  is an index which selects a sensor, and  $k=1...N$  is an index which selects the last  $N$  values of  $V_p(r,s)$ . The data analysis flowchart of Figure 11 begins at loop process block 1102 where a downrange index  $r$  is selected. The process then advances to a loop process block 1104 where a sensor index  $s$  is selected. Having selected  $r$  and  $s$ , the process advances to a process block 1106 where the vector  $V_p(r,s,1...N)$  is scanned for a target. A target is determined to exist if the vector  $V_p(r,s,1...N)$  contains at least  $M$  values above a preset threshold. In a preferred embodiment  $N=8$  and  $M=3$ . Thus, the controller decides that a target was detected at the range  $r$ , by the sensor  $s$ , if 3 of the last 8  $V_p$  values obtained were above the threshold.

The process then advances to a process to a loop test block 1108, which selects the next sensor index  $s$ . When the sensor loop, comprising the process blocks 1108 and 1104 has looped through all sensors, the process advances to a loop test block 1110 which selects the next downrange distance index  $r$ . When the downrange loop, comprising the process blocks 1110 and 1102, has looped through all of the range indexes  $r$ , the process advances to a process block 1112. In the process block 1112 the current target distance  $NEW\_RANGE$  corresponding to a target (found in the process block 1106) having the smallest downrange distance is selected and the process ends.

Figure 12 is a flowchart showing the display update process beginning with a decision block 1202 where  $NEW\_RANGE$  is compared to  $OLD\_RANGE$  (the previous target distance). If  $NEW\_RANGE$  is less than  $OLD\_RANGE$ , then the process advances to a process block 1204; otherwise, the process advances to a process block 1208. In the process block 1204 the value of  $OLD\_RANGE$  is set to  $NEW\_RANGE$  and the process advances to a process block 1206. In the process block 1208, the value of  $NEW\_RANGE$  is again compared to  $OLD\_RANGE$ . If  $NEW\_RANGE$  is equal to

OLD\_RANGE, then the process advances to the process block 1206; otherwise, the process advances to a process block 1210.

The display update is based on a display timer. In the process block 1206 the display timer is reset and the process advances to a decision block 1214. In the process block 1208, the display timer is incremented and the process advances to the decision block 1214. In the decision block 1214, the value of the display timer is checked. If the display timer is greater than a maximum, then the process advances to a process block 1212, otherwise; the process advances to a process block 1216. In the process block 1212, the value of OLD\_RANGE is set to infinity and the process advances to the process block 1216. In the process block 1216, the value of OLD\_RANGE is sent to the display 224 and the process ends.

#### Integrated Radar-Tailight Sensors and Current-Carrier Network System

A radar sensor, such as, for example, the radar sensor 202 shown in Figure 2, may be mounted to large trucks, delivery vans, construction vehicles, and semi-trailers, etc. (collectively "trucks"). However, in some circumstances, installation of the radar sensor 202 may be difficult or costly. Thus, the radar sensor may advantageously be integrated into one or more of the existing light assemblies (e.g., taillights, side turn-signal lights, forward turn-signal lights, etc.) found on trucks as shown in Figures 13A-D. Figure 13A shows a conventional tractor 1302 and semi-trailer (trailer) 1304. The tractor 1302 is typical of many large trucks, construction vehicles, etc. in that the running lights, reverse lights, signal lights, and brake lights are all typically integrated into a single left-side taillight assembly 1330 (shown) and a single right-side taillight assembly (not shown). The tractor 1302 may also have turn-signal lights 1335 mounted on a forward portion of the vehicle and the trailer 1304 may have additional turn-signal lights 1337 mounted on the side of the trailer. In the discussion that follows, the integrated radar-taillight assembly will be disclosed in the context of a backup warning radar sensor integrated with a reverse light. One skilled in the art will recognize that a radar sensor in connection with a lane-change aid (integrated with a turn-signal light) is within the scope of the present invention and may be integrated into the taillight assemblies 1330, 1306, etc. and may also be implemented in the turn-signal light assemblies 1335 and 1337. A display 1314 mounted in the cab (i.e., the passenger compartment) of the tractor 1302 provides audio/visual information from the radar sensors to the driver. The display 1314 may also include other displays, such as, for example, the displays 224 shown in Figure 2.

Electrical signals are provided from the tractor 1302 by a cable 1310 to a first portion of a connector 1312. The first portion of the connector 1312 is attached to a second portion of the connector 1312. The second portion of the connector 1312 provides electrical signals to a trailer 1304 via a cable 1308.

Figure 13B is a rear view of the trailer 1304 and shows a left-side reverse light 1306, a right-side reverse light 1307, one or more running lights 1320, and one or more brake lights 1321. Unlike the tractor 1302, many trailers have a separate assembly for the reverse light 1307 and the other taillights.

Figure 13C illustrates a typical example of an integrated taillight assembly 1330. The assembly 1330 is typically provided as a rectangular housing having upper and lower chambers. The upper chamber encloses the reverse

light and is covered by a white or clear lens 1331. The lower chamber encloses the running lights and brake lights and has a red lens 1332.

Some embodiments of the present invention provide easy installation of the radar sensors into a truck or trailer by integrating the radar into the existing style and form-factors of the taillight assemblies 1306, 1307, and 1330. Power for the taillight assemblies 1306, 1307, and 1330 (as well as the other taillights on the trailer) is provided through the connector 1312. The configuration and number of electrical signal lines provided by the connector 1312 are standardized so that one tractor 1302 can be attached to virtually any trailer 1304. Thus, some embodiments of the present invention also provide easy integration of the radar sensor into the existing truck wiring by using current-carrier networking to provide data communications between the radar-taillight assemblies and a central control unit. The existing truck wiring, including the cables 1310 and 1308 and the connector 1312, are used to carry data between the integrated radar-taillight sensor and a central control unit.

Figure 14 is a block diagram of a complete truck radar-taillight system that uses current-carrier networking to communicate between a central control unit 1402 and four radar-taillight sensor units 1420, 1430, 1440, and 1450. The radar-taillight unit 1420 comprises a radar sensor unit 1421 and a reverse light 1422. In a preferred embodiment, the radar sensor unit 1421 receives electrical power from the same wire that provides power to the reverse light 1422. The radar-taillight units 1430, 1440, and 1450 each comprise a radar sensor similar to the radar sensor unit 1421 and a reverse light similar to the reverse light 1422. The radar-taillight units 1440 and 1450 are mounted to the tractor and may replace the typical taillight assembly 1330. The radar-taillight units 1420 and 1430 are mounted on a trailer. For example, the radar-taillight units 1420 and 1430 may replace the typical reverse light assemblies 1306 and 1307 shown in Figure 13B. The radar-taillight assemblies 1420 and 1430 receive power through the connector 1312.

The radar-taillight sensors 1420, 1430, 1440, and 1450 are controlled by a central control unit 1402, which draws power from an electrical system represented by a truck battery 1404. The battery 1404 also provides power to a first contact of a reverse switch 1406. The reverse switch 1406, also known as a reverse sender unit, is usually located in the transmission and activates when the transmission is placed in reverse. A second contact of the reverse switch is provided to a reverse sense input 1405 of the control unit 1402, to a first terminal of a network coupler 1408, to the connector 1312, and to the radar-taillight sensors 1440 and 1450 (collectively the reverse circuit 1407).

A bi-directional data port 1403 on the control unit 1402 is provided to a second terminal of the network coupler 1408. The control unit 1402 also provides data to the audio-visual display 1314. One skilled in the art will recognize that the control unit 1402 and the display 1314 may be combined in a single unit.

The control unit 1402 sends data to the radar sensors, such as the radar sensor 1421, by modulating the data onto an alternating current (AC) carrier to produce a modulated carrier. The modulated carrier is coupled onto the reverse circuit 1407 by the network coupler 1408. The modulated carrier is thus provided to the radar sensors in the taillight assemblies because the reverse circuit 1407 connects to the radar-taillight assemblies.

The radar sensor 1421, provides a network coupler similar to the network coupler 1408. The radar sensor 1421 receives the modulated carrier and extracts the data sent by the control unit 1402. The radar sensor sends data to the control unit 1420 in the same fashion that the control unit 1402 sends data to the sensor 1421, namely, by modulating the data onto a carrier, and then coupling the carrier onto the circuit for the reverse light. The control unit 1402 receives the modulated carrier via the network coupler 1408.

Communication between the central processor and the radar sensors, such as the sensor 1421, may be supported by a number of multiple access techniques, such as, for example, Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA), Carrier Sense Collision Detect Multiple Access (CSCD/MA), token passing techniques, etc.

The sense input 1405 on the control unit 1402 is optional. The sense input 1405 is coupled directly to the second terminal of the reverse switch 1406 so that the control unit 1402 will know when the reverse switch has been activated. In some embodiments, the radar sensor 1421 is not powered until the reverse switch 1406 is activated. Thus, the control unit 1402 may not be able to perform certain configuration, reliability, and maintenance functions involving the radar sensors until the reverse switch is activated. The sense input 1405 provides a convenient way for the control unit 1402 to know that the radar unit 1421 is powered up and should be communicating. Thus, for example, if the control unit 1402 senses that the reverse switch 1406 is closed, but the radar sensor 1421 is not responding, then the control unit 1402 can warn the driver that the radar sensor is malfunctioning.

In other embodiments, the radar sensor 1421 is continuously powered and the radar sensor 1421 provides switching circuits to turn the lamp 1422 on and off in response to commands from the central control unit 1402.

In yet other embodiments, the control unit 1402 may provide a continuous, low power, carrier signal to the radar sensor 1421. The low power signal is desirably too low in voltage to cause the lamp 1422 to glow, but high enough in voltage to operate the communication function circuits in the radar sensor 1421. The radar sensor 1421 extracts the low power signal, rectifies and filters the extracted signal, and provides the rectified and filtered signal to a dc-to-dc converter. The dc-to-dc converter provides sufficient voltage to operate portions of the radar sensor 1421. Alternatively, the radar sensor 1421 may use a transformer to step the unmodulated carrier from a low voltage to a higher voltage that is then rectified and filtered to provide power for the radar sensor 1421.

Figures 15A-G show various embodiments of the integrated radar-taillight assembly. Figure 15A shows an integrated radar-taillight assembly 1500 to replace the taillight 1330 shown in Figure 13. The taillights 1330 and 1500 provide a reverse light, a running light, and a brake light. The assembly 1500 includes a housing 1502 having upper and lower compartments. The upper compartment contains a reverse lamp 1510 mounted in front of a reflector 1508. Light from the reverse lamp 1510 shines through a clear (or white) lens 1504. The lower compartment contains a running/braking lamp 1512 mounted in front of a reflector 1514. The lamp 1512 typically has two filaments, a first filament is used for the running light, and a second filament, or both filaments together, for the brake light. Light from the running/braking lamp 1512 shines through a red lens 1506. A transmitting radar antenna 1517 and a receiving radar



antenna 1518 are mounted in front of the reflector 1514. ElectroMagnetic (EM) radiation from the radar antennas 1517 and 1518 passes through the lens 1506 with little attenuation, thereby allowing the antennas 1517 and 1518 to "see" through the lens 1506.

5 In one embodiment, the antennas 1517 and 1518 are patch antennas that are conformal to the surface of the reflector 1506 and separated from the reflector by a thin layer of dielectric material. The surfaces of the patch antennas may be painted white or coated with a shiny material (e.g., tin) and polished so that the antennas 1517 and 1518 reflect light from the lamp 1512.

10 In another embodiment, the antennas 1517 and 1518 may be antennas (e.g., dipoles) that are mounted to the back of the lens 1506. In yet another embodiment, the antennas 1517 and 1518 are slot antennas, being slots made in a wire grid. The wire grid (i.e., a wire screen) functions as a ground plane at radar frequencies and yet allows light from the lamp 1512 to pass through.

15 The antennas 1517 and 1518 are operably connected to a radar circuit board 1516 mounted behind the reflector 1514. The reflector 1514 acts like a heat shield to keep heat generated by the lamp 1512 away from the electronic components mounted on the circuit board. The electronic components for the radar sensor are mounted on the radar circuit board 1516. The radar circuit board 1516 is shown in the lower compartment of the housing 1502 because the lower compartment is usually much larger than the upper compartment. One skilled in the art will recognize that the radar circuit board 1516 may also be placed in both compartments or in the upper compartment as well.

20 Wire leads 1520-1523 provide connections for ground, reverse light, brake light, and running light respectively. The leads 1522 and 1523 are provided to the lamp 1512. The leads 1522 and 1523 may also be provided to the radar circuit board 1516 to allow the radar circuit board 1516 to sense the filament voltages of the lamp 1512. The lead 1521 is provided to the radar circuit board 1516 and to the reverse lamp 1510. The ground lead 1520 is provided to the lamp 1512, the lamp 1510, and the radar circuit board 1516.

25 The radar circuit board 1516 provides the radar sensor and communications functions as described in connection with Figure 16. Radio Frequency (RF) signals generated by the radar circuit board 1516 are provided to the transmitting antenna 1517, which radiates ElectroMagnetic (EM) waves through the lens 1506 and into the space behind the taillight assembly 1500. The EM waves are reflected by targets behind the assembly 1500. The reflected waves pass through the lens 1506 and are received by the receiving antenna 1518. The receiving antenna converts the EM waves into RF currents that are provided to the radar circuit board 1516.

30 An optional optical sensor 1503 may be provided in the upper chamber of the housing 1502 and an optional optical sensor 1505 may be provided in the lower chamber of the housing 1502. The optical sensors 1503 and 1505 each provide a signal to the radar circuit board 1516 in response to light from the lamps 1510 and 1512 respectively. Alternatively, the sensors 1503 and 1505 may be current sensors that sense the current through the lamps 1510 and 1512. Using information from the sensors 1503 and 1505, the communication circuits in the radar circuit board 1516 send a warning to the driver if the lamps malfunction.

The lamp 1512 has a filament for the running light and thus may be on for long periods of time. Heat from the filament will cause the temperature inside the housing 1502 to rise significantly. Moreover, the lamp 1512 has an additional filament that is used in connection with the brake light. When the brake lights are activated, the lamp 1512 is operating in a higher output mode and is producing even more heat. Thus, even though the brake lights may not be used as much as the running lights, operation of the brake lights can produce a significant heat rise in the housing 1502. Tests indicate that the lamp 1512 can cause a temperature rise of over 100 degrees Celsius inside the housing 1502. This temperature will cause the temperature of electronic equipment, such as the radar circuit board 1516, to rise and thereby possibly adversely affect the operation of the radar sensor.

Replacing the lamp 1512 with an array of Light Emitting Diodes (LEDs) can reduce the temperature rise caused by the lamp 1512. Figures 15B and 15C show side and front views of an alternate embodiment of an integrated radar-taillight assembly 1530 to replace the taillight 1330 shown in Figure 13. The assembly 1530 is similar to the assembly 1500 in many respects, except that in the assembly 1530, the lamp 1512 and the reflector 1514 are replaced by an array of red LEDs. LEDs produce less heat than an incandescent lamp and thus produce a smaller heat rise inside the housing 1502. Tests indicate that an array of LEDs cause the temperature inside the housing 1502 to rise only a few degrees Celsius. Advantageously, the LEDs have a much longer useful life than an incandescent lamp. The array of LEDs also provides considerable fault tolerance, since the failure of a few LEDs in an array of LEDs will not significantly affect the total light output of the array.

The assembly 1530 includes the housing 1502 having upper and lower compartments. The upper compartment contains the reverse lamp 1510 mounted in front of the reflector 1508. Light from the reverse lamp 1510 shines through the lens 1540. The lower compartment contains the array of LEDs mounted to an LED circuit board 1531. The array of LEDs is wired to provide two light output levels, a lower output level for the running light and a higher level for the brake light. Light from the array shines through the red lens 1506. A transmitting radar antenna 1536 and a receiving radar antenna 1534 are provided on the surface of the LED circuit board 1531. The antennas 1534 and 1536 are preferably printed circuit type antennas such as patch antennas or printed dipole antennas. The LED circuit board 1531 is preferably a three-layer circuit board having first, second, and third layers of conductors. The first layer of conductors is the outer layer (near the array of LEDs) and provides the patch antennas 1534 and 1536. The second layer is a ground plane layer for the patch antennas. The third layer provides circuit connections for the array of LEDs.

In another embodiment the antennas 1534 and 1536 are mounted to the back of the lens 1506 or mounted in the space between the LED circuit board 1531 and the lens 1506. In yet another embodiment, the antennas 1534 and 1536 are slot antennas, being slots made in a wire grid.

The radar circuit board 1516 is mounted behind the LED circuit board 1531 and the antennas 1534 and 1536 are operably connected to the radar circuit board 1516. One skilled in the art will recognize that the radar circuit board 1516 and the LED circuit board 1531 may be combined. The electronic components for the radar sensor are mounted on

the radar circuit board 1516. One skilled in the art will recognize that the radar circuit board 1516 and/or the antennas 1534 and 1536 may also be place in separate compartments, upper compartment, etc.

Wire leads 1520-1523 provide connections for ground, reverse light, brake light, and running light respectively. The leads 1522 and 1523 are provided to the LED circuit board 1531 to power the LEDs. The lead 1521 is provided to the radar circuit board 1516 and to the reverse lamp 1510. The ground lead 1520 is provided to the LED circuit board 1531, the lamp 1510 and the radar circuit board 1516.

The radar circuit board 1516 provides the radar sensor and communications functions as described in connection with Figure 16. The optional optical (or current) sensor 1503 may be provided in the upper chamber of the housing 1502. An optional optical (or current) sensor 1505 may also be provided in the lower chamber of the housing 1502. Outputs from the sensors 1503 and 1505 are provided to the radar circuit board 1516 and the communication circuits in the radar circuit board 1516 send a warning to the driver if the lamp 1510 or LEDs malfunction.

Figures 15D and 15E show side and front views of an integrated radar-taillight assembly 1550 to replace the reverse taillight 1306 (and 1307) shown in Figure 13. The reverse taillight 1306 provides a reverse light only. The assembly 1550 includes a housing 1555 containing a reverse lamp 1554 mounted in front of a reflector 1556. Light from the reverse lamp 1554 shines through a clear (or white) lens 1553. A transmitting radar antenna 1558 and a receiving radar antenna 1560 are mounted in front of the reflector 1556. ElectroMagnetic (EM) radiation from the radar antennas 1558 and 1560 passes through the lens 1553 with little attenuation, thereby allowing the antennas 1556 and 1558 to radiate.

In one embodiment, the antennas 1556 and 1558 are patch antennas, similar to the patch antennas 1517 and 1518, that are conformal to the surface of the reflector 1506 and separated from the reflector by a thin layer of dielectric material.

In another embodiment the antennas 1558 and 1560 may be mounted to the back of the lens 1553. In yet another embodiment, the antennas 1558 and 1560 are slot antennas, being slots made in a wire grid.

The antennas 1558 and 1560 are operably connected to the radar circuit board 1516 mounted behind the reflector 1553. The reflector 1553 acts like a heat shield to keep heat generated by the lamp 1553 away from the electronic components mounted on the circuit board. The electronic components for the radar sensor are mounted on the radar circuit board 1516. Wire leads 1551 and 1552 provide connections for ground and reverse light respectively. The lead 1552 is provided to the radar circuit board 1516 and to the reverse lamp 1554. The ground lead 1551 is provided to the lamp 1554, and the radar circuit board 1516.

The optional sensor 1503 provides a signal to the radar circuit board 1516 in response to the lamp 1554. The communication circuits in the radar circuit board 1516 send a warning to the driver if the lamp 1554 malfunctions.

Figures 15F and 15G show side and front views of an alternate embodiment of an integrated radar-taillight assembly 1580 to replace the taillight 1306 shown in Figure 13. The assembly 1580 is similar to the assembly 1550 in many respects, except that in the assembly 1580, the lamp 1554 and the reflector 1556 are replaced by an array of white

Light Emitting Diodes (LEDs). The lamp 1554 may take several milliseconds to warm-up. During the warm-up period the lamp 1554 draws a heavy current that may interfere with the operation of the radar circuit board 1516. LEDs, in addition to the other qualities listed above, provide almost instant on capability, with little or no initial current surge. Thus, the use of LEDs keeps the housing 1555 cooler and provides better startup current conditions for the radar circuit board 1516.

5           The assembly 1580 includes the housing 1555 and an array of LEDs mounted on an LED circuit board 1571. Light from the LEDs shines through the lens 1553. A radar antenna 1575 and a radar antenna 1576 are provided on the surface of the LED circuit board. The antennas 1534 and 1536 are similar to the antennas 1536 and 1534 discussed in connection with Figures 15B and 15C. Construction of the LED circuit board 1571 is similar to construction of the LED circuit board 1531 also discussed in connection with Figures 15B and 15C.

10           In other embodiments, the antennas 1575 and 1576 may be slot or dipole antennas mounted behind the lens 1553.

          Wire leads 1551 and 1552 provide connections for ground and reverse light, respectively. The lead 1552 is provided to the radar circuit board 1516 and to the LED circuit board 1571. The ground lead 1551 is provided to the LED circuit board 1571 and to the radar circuit board 1516.

15           Figure 16 is a block diagram of a radar sensor 1600 showing one embodiment of the functions provided by the radar circuit board 1516. A V+ input 1512 provides power and current-carrier signals to the radar circuit board 1516. The V+ input 1512 may be provided by the reverse light circuit 1407, as shown in Figure 14. A ground connection is provided by a ground input 1514. The V+ input 1512 is provided to an input of a power filtering and conditioning block 1602 and to a first input/output port of a network coupler 1604. The network coupler 1604 provides extraction (input) and insertion (output) of a modulated carrier signal onto the V+ input 1512. A second input/output port of the network  
20           coupler 1604 is provided to a first port of a filtering and signal conditioning block 1606. A second port of the filtering and conditioning block 1606 is provided to an input/output port of a data modulation/demodulation block 1608. A data output of the data modulation/demodulation block 1608 is provided to a coded data input of a data coding/decoding block 1610 and a coded data output of the data coding/decoding block 1610 is provided to a data input port of the data  
25           modulation/demodulation block 1608. A bi-directional data bus 1611 connects the data coding/decoding block 1610 to a radar section 1612. An RF output of the radar section 1612 is provided to a transmitting antenna 1651 and an RF input of the radar section 1612 is provided by a receiving antenna 1650.

          A power output of the power filtering and conditioning block 1602 is provided to a power input of the network coupler 1604, to a power input of the filtering and signal conditioning block 1606, to a power input of the data  
30           modulation/demodulation block 1608, to a power input of the data coding/decoding block 1610 and to a power input of the radar section 1612. One skilled in the art will recognize that some of the blocks shown in Figure 16, such as the network coupler 1604 and the filtering and signal conditioning block 1606 may, in some embodiments, be constructed from passive components.

The power supplied to the V+ input 1501 is often "dirty" power containing engine noise, voltage spikes, current spikes, etc. The power filtering and conditioning block 1602 converts the dirty power from the V+ input 1501 into clean power at the power output port. The clean power is used to operate the active circuits in the radar sensor 1600.

5 The blocks 1604, 1606 and 1608 and 1610 comprise a network interface 1601 between the V+ input 1512 and the radar section 1612. When the network interface 1601 is receiving data, the network coupler 1604 extracts modulated carrier signals from the V+ input 1512. When the network interface 1601 is transmitting data, the network coupler 1604 inserts a modulated carrier signal on the V+ input. In one embodiment, the network coupler 1640 comprises a series capacitor that connects the first input/output port of the network coupler 1640 to the second input/output port of the network coupler 1640. In other embodiments, the network coupler comprises impedance matching elements, such as,  
10 for example, a transformer, to match the impedance of the V+ input 1512 to the impedance of the filtering and signal conditioning block 1606. In other embodiments, the network coupler 1604 comprises active elements to provide signal amplification and conditioning. The filtering and signal conditioning block 1606 provides additional signal processing to clean up input signals extracted by the network coupler and to prepare output signals for insertion onto the V+ port.

In one embodiment, portions of the network interface 1601 are implemented using an SSC P111 Power Line (PL) Media Interface Integrated Circuit (IC) and an SSC P200 PL Network Interface IC, both manufactured by the Intellon Corp.  
15 In another embodiment, portions of the network interface 1601 are implemented using a PLT-21 transceiver manufactured by the Echelon Co., and an MC143120B1 processor manufactured by Motorola, Inc.

The data modulation/demodulation block 1608 demodulates the modulated carrier signals received from the network coupler 1604 and provides the demodulated (but still coded) data to the data coding/decoding block 1610. In other words, the modulation/demodulation block 1608 does not interpret the data, but rather provides the stream of demodulated data bits to the data coding/decoding block 1610. Likewise, the modulation/demodulation block 1610 receives coded data from the data coding/decoding block 1610 and modulates the data onto the transmission carrier.  
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The data coding/decoding block 1610 interprets the data received from the modulation/demodulation block 1608. In the block 1610, the demodulated bit stream is separated into packets and interpreted. In one embodiment, the packets contain address bits and data bits. Each radar sensor 1600 is assigned an address so that the control unit 1402 can send specific commands to specific radar sensors. If the address bits in a packet match the address of the radar sensor 1600, then the data bits from that packet are interpreted as commands and data for the radar sensor 1600. The control unit 1402 may also send broadcast packets, which are received by all sensor units. The data coding/decoding block 1610 also collects commands and data into packets (each comprising an address and data) that are to be sent to other radar sensors or to the control unit 1402.  
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The radar section 1612 provides the actual radar functionality. In one embodiment, the radar section 1612 is embodied by the radar section 402 shown in Figure 4. In this embodiment, the bi-directional bus 1611 comprises the TX signal 410, the RX signal 412 and the IF signal 414 shown in Figure 4. The central control unit 1402 send TX and RX

commands (corresponding to the TX and RX signal lines) to the radar sensor 1600, and the radar sensor unit 1600 sends IF commands (corresponding to digitized data from the IF line) back to the central control unit 1402.

In another embodiment, the radar section 1612 is embodied by the radar section 402 and the Analog Section 404 shown in Figure 4. In this embodiment, the bi-directional data bus 1611 comprises the signal lines 420, 421, 422, 424, 426 and 428 shown in Figure 4. The central control unit sends SENSOR ENABLE, PROG ENABLE, PROG CLK and PROG DATA IN commands to the radar sensor 1600 and the sensor 1600 responds with digitized ANALOG data and PROG DATA OUT commands.

In another embodiment, the radar section is embodied by the RF section 402, the Analog Section 404, and the controller section 408 shown in Figure 4. In this embodiment, the bi-directional data bus 1611 comprises the vehicle input bus 430 and the display bus 432 shown in Figure 4. The central control unit sends vehicle input commands to the radar sensor 1600, and the sensor 1600 responds with target information and/or display commands.

#### Intelligent Backup Warning Device

In another embodiment of the present invention, the audible warning device 122, illustrated in Figure 1, is an intelligent warning device comprising an audible alarm and the network interface 1601. The intelligent warning device may receive commands from the central control unit 1402 and/or a sensor, such as the radar sensor 1600. The commands received by the intelligent warning device 122 may instruct the warning device to warble, to change pitch, to change volume, etc. to more effectively warn of danger. For example, the worker 124 shown in Figure 1, upon hearing the warning device 122 change to a different sound, would realize that he was in danger of being injured. The backup warning device 122 is powered by the reverse circuit 1407. Thus, providing the audible warning device 122 with the network interface 1601 allows the central control unit 1402, or the radar sensors 1600, to send commands to the warning device 122.

#### Improved Data Efficiency in an Automotive Ranging Radar

Some of the desirable qualities of a high-performance vehicular radar system include low cost, good manufacturability, and stable operation over time and temperature. Manufacturability and stability can be improved by replacing analog processing with digital processing. However, the data processing and communication requirements in a digital system can become unwieldy if measures are not taken to control the amount of data produced. One way to reduce the cost of the system is to reduce the amount of digital data that is produced and processed by the radar system. In a preferred embodiment, the amount of digital data is reduced by controlling the number of analog-to-digital conversions. Preferably, digital samples are produced during desired time periods corresponding to desired target ranges and digital samples are not produced during other periods corresponding to other target ranges. Reducing the amount of data, reduces system cost and complexity by allowing a simpler, slower, DSP to be used to process the data.

Figure 17 shows one embodiment of a low-cost computer-based radar system 1700 similar to the system shown in Figure 4. The system 1700 produces a detector signal from an Intermediate Frequency (IF) signal by using

fast analog sampling followed by lowpass filtering and slow digital sampling. The system 1700 comprises an antenna section 1702, an RF section 1704, a signal processor section 1706 and a controller 1708. In the system 1700, a switched-analog detector signal 1765 is provided to the controller 1708 such that the controller 1708 need only perform digital-to-analog conversions during a desired time period when the detector signal is expected to contain target information on desired targets.

The antenna section 1702 includes a transmit antenna 1710 and a receive antenna 1712. An RF output signal from the RF section 1704 is provided to the transmit antenna 1710. An output of the receive antenna 1712 is provided to an RF input of the RF section 1704.

The RF section 1704 sends RF transmit pulses to the transmitting antenna 1710 in response to transmit command pulses from the signal processing section 1706. The transmit command pulses from the signal processing section 1706 are provided to a control input of a SPST RF switch 1714. A first terminal of the SPST RF switch 1714 is provided to the transmit output of the RF section 1704.

Inside the RF section 1704, an output from an RF oscillator 1720 is provided to an input of a transmit RF amplifier 1718 and to an input of a local oscillator (LO) RF amplifier 1722. An output of the LO RF amplifier 1722 is provided to a first input of a mixer 1726. The mixer 1726 is used as a downconverter to convert the RF frequency radar signal into an Intermediate Frequency (IF) signal. The receiver input of the RF section 1704 is provided to an input of a Low Noise Amplifier (LNA) 1724. An output of the LNA 1724 is provided to a second input of the mixer 1726. An output from the mixer 1726 is provided to IF output of the RF section 1704.

An output of the transmit amplifier 1718 is provided to an input of a programmable attenuator 1716. An output of the programmable attenuator 1716 is provided to a second terminal of the SPST switch 1714. An RF attenuation command from the controller 1708 is provided to a control input of the programmable attenuator 1716.

Inside the signal processor section 1706, an output from a first Pulse Repetition Frequency (PRF) oscillator 1736 is provided to an input of a control gate 1734. An output from a second PRF oscillator 1740 is provided to an input of a second control gate 1738. An output from the control gate 1734 is provided to a trigger input of a monostable multivibrator (one-shot) 1732 and to a signal input of a programmable delay 1742. An output of the one-shot 1732 is provided to an input of a switch driver buffer 1730. An output from the buffer 1730 is provided to the transmit control output of the signal processor section 1706. A transmit pulse width control output from the controller 1708 is provided to a pulse width control input of the one-shot 1732. A first oscillator selector output from the controller 1708 is provided to a control input of the gate 1734. A second oscillator control output from the controller 1708 is provided to a control input of the gate 1738.

A delayed signal output from the programmable delay 1742 is provided to a trigger input of a one-shot 1744. A switched output from the one-shot 1744 is provided to a switch driver buffer 1746. An output from the buffer 1746 is provided to a control input of a SPST switch 1754. A receive pulse width control output from the controller 1708 is provided to a pulse width control input of the one-shot 1744.

The IF output from the RF section 1704 is provided to an input of a bandpass filter 1750. An output from the bandpass filter 1750 is provided to an input of an amplifier 1752. An output of the amplifier 1752 is provided to a first terminal of the SPST switch 1754. A second terminal of the SPST switch 1754 is provided to an input of a low-pass amplifier 1756. An output from the low-pass amplifier 1756 is provided to a first terminal of a SPST switch 1748 and to an input of a programmable gain block 1760.

A second terminal of the SPST switch 1748 is provided to ground. A detector control signal from the controller 1708 is provided to a control input of the SPST switch 1748.

An output from the programmable gain stage 1760 is provided to a two stage amplifier comprising a first amplifier 1762 and a level shifter 1764. An output of the level shifter 1764 is provided to an analog detector signal input of the controller 1708.

Programming for the controller 1708 is provided by a program memory 1766, which may comprise a Read Only Memory (ROM), an Electrically-Erasable Programmable Read Only Memory (EEPROM), a flash memory, a random access memory, and the like. Information comprising programs and data is provided from the program memory 1766 to the controller 1708.

In one embodiment, the radar system 1700 exchanges data with other devices in the vehicle by modulating the data onto and off of a power line as described in connection with Figure 13. Thus, the radar system 1700 in Figure 17 depicts a power connector 1772 connected to a vehicle power cable. A power output from the connector 1772 is provided to an input of a voltage regulator and power conditioner 1774. One or more outputs from the regulator 1774 are provided to power inputs of the controller 1708, the signal processing section 1706, and the RF section 1704.

A first bi-directional data output from the connector 1772 is provided to an input of a user information control block 1768. An output from the user information control block 1768 is provided to a user control input of the controller 1708. A second bi-directional data output from the connector is provided to an input of an data communication block 1770. An output from the data communication block 1768 is provided to a data input of the controller 1708.

The RF section 1704, signal processor 1706, and controller 1708 function in a manner similar to the RF section 402, analog section 404, and controller section 406 described in connection with Figure 4. The analog sampling switch 1754 provides analog samples of the IF signal to the lowpass amplifier 1756. The filtered samples are amplified and provided as an analog detector signal to an analog detector signal input of the controller 1708. In one embodiment, the controller 1708 includes an analog-to-digital converter to convert the analog detector signal into a digital data signal.

Analog components, such as the analog sampling switch 1754 and the lowpass amplifier 1756 are often troublesome to manufacture and may introduce operational stability problems due to long-term drift, temperature sensitivity, etc. Figure 18 shows one embodiment of a digital signal processor (DSP) based radar system 1800. The



system 1800 uses fast digital sampling and a digital detector in a Digital Signal Processor (DSP) in place of the analog fast sampling detector in the system 1700. The system 1800 is, for the most part, similar to the system 1700 and includes the antenna section 1702, the RF section 1704 and the controller 1708 shown in Figure 17. The system 1800 includes a signal processor section 1806 that is similar to the signal processor section 1706 with a few alterations. In the signal processor 1806, the IF output from the RF section 1704 is provided to an input of a lowpass filter 1810. An output from the lowpass filter 1810 is provided to an input of a programmable gain amplifier 1812. An output from the programmable gain amplifier 1812 is provided to an analog input of a fast analog-to-digital (A/D) converter 1816. An output from the programmable delay 1742 is provided to a control input of the A/D converter 1816. A digital output from the analog-to-digital converter 1816 is provided to a first input of a DSP 1820. A digital output from the DSP 1820 is provided to a digital detector input of the controller 1708. A gain control output from the controller 1708 is provided to a gain control input of the gain-controlled amplifier 1812.

The A/D converter 1816 converts the filtered analog IF signal into digital samples in response to a control signal from the time delay 1742. The DSP 1820 processes the digital samples (corresponding to a desired target range), thereby reducing the number of digital samples. Reducing the number of digital samples reduces the amount of data that the DSP will have to process, thereby reducing the complexity and cost of the system 1800 by allowing a simpler, less-expensive, DSP to be used.

The radar system 1800 provides a higher level of functionality than the system 1700 owing to the signal processing capabilities of the DSP 1820. The DSP provides signal processing on the digitized IF signal and provides the processed data to the controller 1708. In one embodiment, the DSP provides signal processing, including, for example, digital filtering, to extract information regarding targets from the digital samples. The digital filtering may include finite impulse response filters, infinite impulse response filters, non-linear filters, etc. The use of digital filtering provides more versatility and less time delay than the filtering provided by analog filtering.

The DSP 1820 provides a high level of functionality, but at a cost. Figure 19A is a block diagram of a radar system 1900 that reduces the cost of signal processing as compared to the system 1800 by eliminating the DSP 1820. The system 1900 is, for the most part, similar to the system 1700 and includes the antenna section 1702, the RF section 1704 and the controller 1708 shown in Figure 17. The system 1900 includes a signal processor section 1906 that is similar to the signal processor section 1706 with a few alterations. In the signal processor 1906, the IF output from the RF section 1704 is provided to an input of the lowpass filter 1810. An output from the lowpass filter 1810 is provided to an input of a programmable gain amplifier 1812. An output from the programmable gain amplifier 1812 is provided to an analog input of an analog-to-digital (A/D) converter 1920. An output from the programmable delay 1742 is provided to a control input of the A/D converter 1920. A digital output from the A/D converter 1920 is provided to a digital data input of the controller 1708.

The radar system 1900 reduces the amount of digital data processing by reducing the number of digital samples. The A/D converter 1920 converts the filtered analog IF signal into digital samples in response to a trigger

pulse rather than at regular intervals. This limits the number of digital data samples provided to the controller 1708 to the samples that are most useful. The output from the programmable delay 1742 controls the operation of the A/D converter 1920 such that the A/D converter 1920 provides digital output samples during desired time periods. The desired time periods are selected by the programmable delay 1742 and correspond to desired target ranges.

5 As discussed above, the system 1700 uses fast analog sampling (provided by the switches 1754 and 1748) followed by lowpass filtering (provided by the amplifier 1756). The lowpass filtering is followed by amplification and slow digital sampling. The systems 1800 and 1900 use fast digital sampling. Thus, the systems 1800 and 1900 provide a simplified system block diagram, resulting in overall reduced cost. The fast digital sampling system can be implemented "on-chip" with fewer capacitors and other analog components. This makes the digital sampling system  
10 more manufacturable, more reliable, and more stable than analog designs. The digital sampling system is easily implemented using one or two simple integrated circuits with a small number of external components.

The DSP-based system 1800 and the controlled A/D-based system 1900 provide digital samples in response to commands from the controller 1708 rather than relying on a hardware PRF (Pulse Repetition Frequency). This configuration allows the processor to implement dithering and other signal-enhancing algorithms efficiently. Also,  
15 since range readings are available immediately, the system can provide a faster and more accurate response than analog-based systems. Since the controller 1708 can obtain digital data "at will," the processing requirements are reduced, depending on the application requirements.

Figure 19B is a flowchart showing the operations performed by the controller 1708 to obtain digital radar data in the systems 1800 and 1900. The flowchart begins at a process block 1949 where the controller 1708 sets  
20 the transmit attenuation in the programmable attenuator 1716, thereby effectively establishing the transmitter power. Higher powers are used for long ranges and lower powers are used for short ranges. After setting the transmit power, the process advances to a process block 1950 where the controller 1708 sets a width of the transmit pulses generated by the one-shot 1732. Relatively longer pulse widths are used for long ranges and relatively shorter pulses are used for shorter ranges. After setting the transmit pulse width, the process advances to a process block 1952  
25 where the controller 1708 selects a PRF by selecting either the PRF oscillator 1736 or the PRF oscillator 1740. A relatively faster PRF is used for targets at shorter distances and a relatively slower PRF is used for targets at longer distances. After selecting a PRF, the process advances to a process block 1954 where the controller 1708 selects a minimum target range by programming a time delay into the programmable time delay 1742. Relatively longer delays correspond to relatively larger minimum target ranges. After setting the minimum target distance, the process  
30 advances to a process block 1956 where the controller 1708 sets the receiver gain by programming the programmable gain block 1760. Typically, higher gains are used in connection with longer ranges and smaller targets.

After setting the receiver gain the process advances to a process block 1958 where the controller 1708 collects a group of digital data samples from the signal processor. The PRF oscillators 1734 and 1740 are typically free-running oscillators that continually produce transmit pulses. The continuous train of transmit pulses results in a

continuous train of received analog data that is provided to the A/D converters 1816, 1920. The delay set in the programmable delay 1742 determines which of the digital A/D outputs are processed.

After obtaining a group of digital data samples selected in the process block 1958, the process advances to a process block 1960. In the process block 1960, the digital samples are analyzed to extract target range and Doppler information. The process then advances to a process block 1962 where the target data is sent to the user interface display controller. After sending the data, the process advances to a decision block 1964 where the process determines whether or not the operating parameters need to be adjusted. If the parameters do need adjustment, then the process jumps back to the process block 1949, otherwise; the process jumps back to the process block 1958 to obtain more target data.

#### Speed-Sensitive Lane-Change Aid System

As discussed above in connection with Figure 2, radar systems that detect objects (targets) in a driver's blindspot can help make lane-change maneuvers safer for all and less stressful for the driver. Desirably, lane-change radars, such as the radar units 208 and 210 shown in Figure 2 detect vehicles in the adjacent lane, but do not false-trigger on vehicles two lanes over, or false trigger on stationary objects such as parked vehicles, barriers, posts, lamps, trees, and the like, that may pass through the radar's field of view. One aspect of the present invention is a radar system that reduces the number of false alarms by using the speed of the driver's vehicle to control some aspects of the operation of the lane-change aid system.

Figure 20 shows a lane-change aid system comprising a radar sensor 2002, a speedometer pick-up 2004, a turn-signal pick-up 2008, and a user interface 2010. The user interface 2010 includes a control unit, such as the control unit 222 shown in Figure 2 or the control unit 1402 shown in Figure 14. The user interface also includes one or more displays such as the display 224 shown in Figure 2 or the display 1314 shown in Figures 13 and 14.

The speedometer pick-up 2004 provides vehicle speed information to the user interface 2010. In one embodiment, user interface 2010 obtains information from the speedometer pick-up 2004 via a vehicle information bus. The turn-signal pick-up provides turn-signal information to the user interface 2010. The radar sensor 2002 (such as for example, the radar 208 shown in Figure 2, or the radar 1421 shown in Figure 14) measures targets based on target range and optionally target Doppler (velocity) as discussed in connection with Figure 10. In one embodiment, the radar sensor 2002 comprises a vehicle left side sensor and a vehicle right side sensor as shown in Figure 2. Communication between one or more of the blocks shown in Figure 2000, including the user interface 2010, the turn-signal pick-up 2008, the speedometer pick-up 2004 and the radar sensor 2002 may be provided by data modulated onto the vehicle power lines as described in connection with Figures 16 or by other communication systems.

As indicated, the radar sensor 2002 preferably measures distance to target and the system 2002 is able to distinguish between multiple targets on the basis of range and Doppler. This allows the lane-change system to distinguish between distant closer objects. For example, range detection allows the system 2000 to distinguish between a motorcycle in the adjacent lane and a bus two lanes over.

To further reduce false triggers, especially in city driving, the lane change aid system 2000 uses the speed of the vehicle. In one embodiment, the lane-change system uses Doppler processing as discussed in connection with Figure 16 to determine vehicle speed. In another embodiment the lane-change system receives vehicle speed information from the speedometer pick-up 2004. The system 2000 preferably reduces the maximum detection range at lower speeds. In one embodiment, the system 2000 provides a maximum range of about 9 feet above 45 mph (miles per hour), a maximum range of about 6 feet from 25 to 45 mph, and a maximum of about 3 feet from 15 to 25 mph, and below 10 mph the system ignores all targets. The system 2000 preferably estimates the speed of a target by measuring the relative speed between the target and the vehicle (by measuring the Doppler shift of the radar signal received from the target) and then subtracting the actual speed of the vehicle from the relative speed. These system 2000 warns the driver about targets that are moving at approximately the same speed as the vehicle (i.e., low Doppler targets). The system 200 does not warn the driver about targets that are stationary or moving at a slow speed (i.e., high Doppler targets).

Alternately, the system 2000 may reject all targets that have a relative speed (the speed relative to the speed of the vehicle) above some fixed amount. That is, targets with a large Doppler may be rejected on the assumption that they are not vehicles in adjacent lanes but rather fixed objects near the lane. Rejecting targets with a large Doppler does not necessarily require data from the speedometer pick-up 2004, and is thus useful when the speedometer pick-up 2004 is omitted or malfunctioning.

In one embodiment, the user interface 2010 includes one or more audible warning devices and one or more visual warning devices. Suitable audible warning devices include buzzers, loudspeakers, tone generators, and the like. Suitable visual warning devices include lights, light emitting diodes, fluorescent displays, plasma displays, heads-up displays, computer displays, dashboard indicators, mirror indicators, and the like. Typically, the visual warning devices are active at all times (or when the vehicle is travelling above some selected minimum speed) in order to give the driver information about cars in the driver's blindspot. However, in order to avoid annoying the driver, the audible warning devices are typically only active when the driver is actually trying to change lanes and the radar detects a vehicle in the adjacent lane. In one embodiment, the buzzer is enabled when the turn-signal pick-up indicates that the driver has activated a turn signal. Table 2 below lists operating parameters for one embodiment of the system 2000

Vehicle Speed	Maximum Radar Sensor Range	Visual Alarm	Audible Alarm
< 15 mph	≈5 ft	Enabled	Disabled
15-25 mph	≈5 ft	Enabled	Enabled
25-45 mph	≈7 ft	Enabled	Enabled
> 45 mph	≈9 ft	Enabled	Enabled

Table 2.

Trailing-Edge Ranging

In one embodiment, the radar systems described herein detect a range to a target by illuminating the target with a pulse of RF energy and receive portions of the pulse reflected by the target. A range search algorithm (such as, for example, the range search algorithms discussed in connection with Figures 10-12 above) detects the target by examining the received portions of the reflected pulse. The range search algorithm detects the received portions of the reflected pulse and calculates the time needed for the pulse to travel from the radar, to the target, and back to the radar. The distance to the target is then calculated by multiplying one half of the measured travel time by the speed of light in air (approximately 1 foot/nanosecond). Thus, for example, if it takes 10 nanoseconds for the pulse to travel from the radar, to the target, and back to the radar, then the target is approximately 5 feet from the radar ( $10 \times 1/2$ ). The factor of one half appears because the pulse travels a round-trip path.

When the pulse returns to the radar from the target, the pulse can be detected either by sensing the leading edge of the pulse, the entire pulse envelope, or the trailing edge of the pulse.

For example, Figure 21 shows a radar 2102 that generates a pulse 2108 having a leading edge 2109 and a trailing edge 2110. The radar 2102 can be any pulsed radar, including any of the radars disclosed herein. The pulse 2108 is transmitted by a transmitting antenna 2104, is reflected by a target 2112, and is received by a receiving antenna 2106. Some coupling typically occurs between the transmitting antenna 2104 and the receiving antenna 2106 such that the receiving antenna 2106 receives both a portion of the pulse 2108 reflected by the target 2112 (the reflected portion), and the receiving antenna receives a portion of the pulse 2108 radiated directly from the transmitting antenna 2104 (the direct portion). The direct portion also includes clutter (reflections) from other components of the radar, such as, for example, the lens 1506 shown in Figure 15A, portions of the vehicle 102 shown in Figure 1, etc. In some cases, the direct portion is of sufficient strength that it becomes difficult to distinguish between the direct portion and the reflected portion. The direct portion typically has zero Doppler and thus is typically not detected as a Doppler-shifted target, but rather, increases the noise floor of the radar system. When the reflection from the target 2112 is relatively weaker than the noise floor, detection of the target 2112 becomes relatively more difficult. Thus, the time-overlap between the direct portion and the reflected portion can make it difficult for a radar to detect targets that are so close that the leading edge 2109 returns to

the receiving antenna 2106 while the transmit antenna 2104 is still transmitting (i.e., before the transmit antenna 2104 has transmitted the trailing edge 2110).

Since the transmitting antenna 2104 and the receiving antenna 2106 are typically in close proximity to one another, the direct portion typically only occurs during the time period when the transmit antenna 2104 is actually transmitting the pulse 2108. In one embodiment, the minimum effective range of the radar is desirably reduced by shortening the pulse duration, where the pulse duration is the length of the pulse 2108 in time. The minimum pulse duration is typically determined by either hardware limitations (i.e., the speed of a transmitter switch such as the switch 508 shown in Figure 5) or bandwidth limitations of the radar system 2112 (because relatively shorter pulses use relatively more bandwidth).

In one embodiment, the minimum effective range of a radar (such as, for example, a radar as discussed in connection with any of Figures 4-20) is desirably reduced by sensing the trailing edge 2110 of the pulse 2108. By the time the trailing edge 2110 is received, the direct component is typically gone (because the transmit antenna 2104 is no longer transmitting). Thus, detecting the trailing edge reduces the minimum useable range of the radar to almost zero.

For example, in a radar with a 10 nanosecond pulse (i.e., 10 nanoseconds between the leading edge 2109 and the trailing edge 2110), the minimum useful detection distance is typically about 5 feet when the leading edge 2109 is used for detection. By contrast, if the trailing edge 2110 is used for detection, the minimum useful detection distance is typically reduced to almost zero feet.

Moreover, when the trailing edge 2110 is used for detection, the minimum useful range of the radar 2102 is not determined by the duration of the pulse 2108. Therefore, the duration of the pulse 2108 can be increased (thereby reducing the bandwidth) without impacting the minimum range of the radar 2102. When only the trailing edge 2110 is used to detect the pulse 2108, the rise time (sharpness) of the leading edge 2109 can be reduced. Reducing the rise time of the leading edge 2109 further reduces the bandwidth of the pulse 2108.

#### Integrated Antenna-Lighting Systems

Figures 15B, 15C, 15F and 15G show radar sensors integrated into automotive lighting assemblies that use arrays of illumination sources such as LED's. In one embodiment, uniform distribution of the light produced by an array of sources is provided by placing the array of sources, and any power supply wires for the sources, in front of the radar antennas in a way that does not overly degrade the performance characteristics of the antennas.

Figures 22A and 22B show an integrated antenna-lighting system wherein one or more antennas are placed behind an array of illumination sources. As shown in Figure 22A, antennas 2208-2211 are disposed behind an array of LEDs. A first terminal of an LED 2230 is provided to a power supply 2224 and a second terminal of the led 2230 is provided to a power supply 2225. The power supply lines 2224-2225 (and other power supply lines provided to the array of LEDs) are oriented such that the power supply lines 2224-2225 are approximately orthogonal to the E-field produced by the antennas 2208-2211. A first bus 2220 connects a first set of the power supply lines, including the power supply 2224 to a first terminal of a power supply. A second bus 2221 connects a second set of the power supply lines, including the

power supply 2225 to a first terminal of a power supply. The power supply lines 2224 and 2225 are either placed on opposite sides of the substrate 1532 or on the same side of the substrate 1532.

The busses 2220 and 2221 are shown oriented orthogonal to the power supply lines 2224-2225 (and thus are parallel to the E-field produced by the antennas 2208-2211). The busses 2220 and 2221 are placed such that they are largely out of the field-of-view of the antennas 2208-2211. In Figure 22A, the busses 2220 and 2221 are placed on opposite sides of the substrate 1532 and placed between the antennas 2208-2211. In Figure 22C, the busses 2220 and 2221 are placed at the edge of the array of LEDs, either on the same side or opposite sides of the substrate 1532.

The LED 2230 and the power supply lines 2224-2225 are mounted on the substrate 1532. In one embodiment, the substrate 1532 is thin as compared to the wavelength of the operational frequencies of the antennas 2208-2211 and the substrate 1532 exhibits relatively low loss at the operational frequencies of the antennas 2208-2211. The antennas 2208-2211 are mounted to a substrate 2204 disposed behind the substrate 1532. The radar circuit board 1516 is provided behind the substrate 2204 and can be attached directly to the substrate 2204. In one embodiment, one or more plated-through holes, such as a plated through hole 2206 connect the antennas 2208-2211 to the radar circuit board 1516.

Since the power supply lines 2224-2225 are orthogonal to the E-field, electromagnetic coupling between the power supply lines 2224-2225 and the E-field will be reduced and thus the presence of the power supply lines 2224-2225 will have relatively little effect on the field pattern, the impedance, the gain, and the efficiency of the antennas 2208-2211. The effect of any perturbations that are produced in the terminal impedance of the antennas 2208-2211 are reduced by adding reactive tuning elements or impedance transformers to the terminals of the antennas 2208-2211.

In one embodiment, the antennas 2208-2211 are rectangular patch antennas that produce an E-field that is approximately horizontally, linearly, polarized. Since the power supply lines 2224-2225 are vertical, the coupling between the E-field and the power supply lines 2224-2225 is reduced and the power supply lines 2224-2225 have a reduced impact on the operating characteristics of the antennas 2224-2225.

#### Other Embodiments

While certain specific embodiments of the present invention have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the present invention.

Although described in terms of separate transmitting and receiving antennas, one skilled in the art will recognize that one antenna can be used for both transmitting and receiving. One or both of the antennas may be loop antennas, dipole antennas, patch antennas, slot antennas, cavity antennas, Yagi antennas, waveguide antennas, traveling wave antennas, leaky wave antennas, wire antennas, spiral antennas, helical antennas, etc.

The operating frequency of the Radio Frequency source 502 may be changed to operate at different frequencies, including for example, frequencies near 36 GHz, 77 GHz, 94 GHz, frequencies from .1 to 300 GHz, etc. The operating frequency of the PRF generator 602 may also be changed to other frequencies. The width of the transmitted pulses of RF energy may be altered and the width of the receive window may be altered.

The visual displays may use any suitable display technology, including, for example, incandescent lamps, light emitting diodes, liquid crystal displays, plasma displays, etc. The audio displays may be constructed using any suitable sound producing technology, including, for example, piezoelectric transducers, loudspeakers, etc.

5 Although described primarily in terms of a backup or side-object warning radar, the radar system described herein is also useful in many other vehicle applications. For example, the present radar may be used inside a passenger compartment: as part of an airbag deployment system; as part of a throttle position system; an active suspension system; etc. The radar system described herein may also be used in other non-vehicle applications, including, for example, home security systems, automatic door opening systems, elevator systems, crossing-light systems, watercraft, aircraft, mobile robots, spacecraft, planetary explorer robots, etc.

10 The network interface may be used with other electronic sensors, including ultrasonic sensors, yaw sensors, velocity sensors, temperature sensors, motion sensors, etc.

Accordingly, the breadth and scope of the present invention should be defined only in accordance with the following claims and their equivalents.



**WHAT IS CLAIMED IS:**

1. An automotive radar capable of tracking and discriminating at least two Doppler shifted targets, said radar comprising:

a radio frequency oscillator;

a transmit pulse generator;

a transmit antenna;

a transmit switch, said transmit switch configured to connect said oscillator to said transmit antenna, said transmit switch operated by an output of said transmit pulse generator;

a receive antenna configured to provide received signals to a downconverter;

a programmable time delay;

a programmable gain amplifier;

a receive switch, an input of said receive switch connected to an output of said downconverter and an output of said switch connected to an input of said programmable gain amplifier, said switch controlled by an output of said programmable time delay; and

a controller operably connected to said transmit pulse generator, said programmable time delay, and said programmable gain amplifier, said controller configured to search for targets at a plurality of downrange regions, for each downrange region, said controller configured to:

set a time delay for said programmable time delay;

set a gain for said programmable gain amplifier; and

trigger said transmit pulse generator.

2. The automotive radar of Claim 1, further comprising a visual display configured to display downrange information about targets detected by said radar.

3. The automotive radar of Claim 2, wherein said visual display is configured to display information about the target which is closest to said radar.

4. The automotive radar of Claim 2, wherein said visual display is configured to display information about targets with a shortest time to impact to said radar.

5. A radar system capable of tracking and discriminating multiple Doppler shifted targets in crossrange and downrange, said radar system comprising:

a plurality of sensor units, each sensor unit comprising a radio frequency transmitter, a radio frequency receiver, a programmable time delay and a programmable gain amplifier; and

a controller unit, said controller unit operably connected to each of said sensor units such that said controller unit can program said programmable time delay and said programmable gain amplifier.

6. The radar system of Claim 5 wherein said controller is further configured to use each of said sensor units to search downrange for targets within the field of view of that sensor unit.

7. The radar system of Claim 5 wherein said controller is further configured to obtain crossrange information by using each of said sensor units to search for targets within the field of view of that sensor unit.

8. The radar system of Claim 5 wherein said plurality of sensor units comprises a first sensor unit, a second sensor unit, and a third sensor unit, said first, second and third sensor units mounted to the rear of a vehicle such that each sensor unit has a field of view which extends behind said vehicle, said first function sensor unit mounted near the centerline of said vehicle, said second sensor unit mounted to the left of said first sensor unit and said third sensor unit mounted to the right of said first sensor unit.

9. The radar system of Claim 5 wherein said plurality of sensor units comprises a first sensor unit and a second sensor unit, said first and second sensor units having a first and second field of view respectively, said first field of view being different from said second field of view.

10. The radar system of Claim 9 wherein a portion of said first field of view overlaps a portion of said second field of view.

11. The radar system of Claim 5 wherein said plurality of sensor units comprises a first sensor unit and a second sensor unit, said first and second sensor units mounted to a vehicle, said vehicle having left and right side-object regions, said first sensor unit having field of view that substantially covers said left side-object region and said second sensor unit having a field of view that substantially covers said right side-object region.

12. The radar system of Claim 5 wherein said controller unit is configured to be operably connectable to a vehicle information bus.

13. The radar system of Claim 12 wherein each of said sensor units is configured to be operably connectable to a vehicle information bus.

14. The radar system of Claim 12 wherein said vehicle information bus carries radar data and data from other vehicle sensors.

15. A method searching for targets to provide downrange information from a pulsed radar system, comprising the steps of:

selecting a range gate;

programming a time delay into a programmable time delay based on said range gate;

programming a gain into a programmable gain amplifier based on said range gate;

transmitting a pulse of radio frequency energy;

receiving reflections of said pulse of radio frequency energy, said reflections produced by said pulse of radio frequency energy being reflected off of target objects;

downconverting said reflections to produce an intermediate frequency (IF) signal; and

supplying a portion of said IF signal to said programmable gain amplifier, said portion selected by said programmable time delay.

16. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said radar sensor comprising:

a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy;

5 a programmable time delay configured select a selected portion of said pulses received by said radio frequency receiver;

a programmable gain amplifier configured to amplify said selected portion; and

a controller unit, said controller unit configured to program said programmable time delay and said programmable gain amplifier to detect targets with a field of view of said sensor at different downrange  
10 distances.

17. The radar sensor of Claim 16, wherein said controller unit is further configure to compute a velocity of said targets.

18. The radar sensor of Claim 16, wherein said controller unit is further configured to compute an acceleration of said targets.

15 19. The radar sensor of Claim 16, wherein said sensor is connected to a information bus.

20. The radar sensor of Claim 19, wherein said sensor supplies information about said targets to an intelligent display connected to said information bus.

21. The radar sensor of Claim 19, wherein said sensor supplies information about said targets to an airbag deployment system.

20 22. The radar sensor of Claim 19, wherein said sensor supplies information about said targets to other vehicle systems connected to said information bus.

23. The radar sensor of Claim 16, wherein said sensor measures a throttle position.

24. The radar sensor of Claim 16, wherein said sensor provides information to an active suspension system.

25 25. The radar sensor of Claim 16, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a target having a second downrange distance.

26. The radar sensor of Claim 16, further comprising an audible warning device configured to project an  
30 audible warning signal, said warning signal projecting a first sound when said radar sensor detects a closest target having a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a closest target having a second downrange distance.

27. The radar sensor of Claim 16, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first velocity, said warning signal projecting a second sound when said radar sensor detects a target having a second velocity.

28. The radar sensor of Claim 16, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first time to impact, said warning signal projecting a second sound when said radar sensor detects a target having a second time to impact.

29. An intelligent display for providing information to a driver of a vehicle, said display comprising:

a sensory display configured to provide sensory information to a driver; and

a control processor operably connected to said sensory display, said control processor configured to receive sensor information from a vehicle information bus, said sensor information comprising data measured by one or more sensors connected to said information bus, said control processor further configured to prioritize said sensor information and to format said display based on said sensor information.

30. The intelligent display of Claim 29, wherein said sensory display provides visual information.

31. The intelligent display of Claim 29, wherein said sensory display provides audible information.

32. The intelligent display of Claim 29, wherein said sensor data comprises radar target data from one or more radar sensors.

33. The intelligent display of Claim 29, wherein said radar sensors are intelligent radar sensor, each intelligent radar sensor comprising a control unit configured to transmit radar target information on said information bus.

34. The intelligent display of Claim 33, wherein said sensory display supplies a first warning display for radar targets having a first time to impact and said sensory display produces a second warning display for radar targets having a second time to impact.

35. An integrated radar sensor and taillight apparatus comprising:

a housing;

a lens covering at least a portion of said housing;

an input connector configured to receive input power from a taillight power circuit;

a taillight mounted in said housing and positioned to allow light from said taillight to shine through said lens; and

a radar sensor mounted in said housing, said radar sensor comprising a network interface, a radar section, and an antenna, said antenna configured to radiate electromagnetic waves through said lens, said network interface configured to:

extract an input modulated carrier signal from said input power;

demodulate said input modulated carrier signal to obtain a data signal, said data signal comprising addresses and commands;

interpret said addresses and commands;

modulate a carrier with output data to produce an output modulated carrier signal; and

insert said output modulated carrier signal into said taillight power circuit.

36. An integrated radar sensor and light apparatus comprising:

a housing;

a lens covering at least a portion of said housing;

a light source mounted in said housing positioned to allow light from said light source to shine through

said lens; and

a radar sensor mounted in said housing, said radar sensor comprising a network interface, a radar section, and a first antenna.

37. The apparatus of Claim 36, wherein said network interface is a current-carrier network interface.

38. The apparatus of Claim 36, wherein said network interface is configured to communicate with a central control unit.

39. The apparatus of Claim 36, wherein said antenna is a patch antenna.

40. The apparatus of Claim 36, wherein said first antenna is a transmit antenna, and said radar section comprises:

a radio frequency oscillator;

a transmit pulse generator;

a transmit switch, said transmit switch configured to connect said oscillator to said transmit antenna, said transmit switch operated by an output of said transmit pulse generator;

a receive antenna configured to provide received signals to a downconverter;

a programmable time delay;

a programmable gain amplifier;

a receive switch, an input of said receive switch connected to an output of said downconverter and an output of said receive switch connected to an input of said programmable gain amplifier, said receive switch controlled by an output of said programmable time delay; and

a controller operably connected to said transmit pulse generator, said programmable time delay, and said programmable gain amplifier, said controller configured to search for targets at a plurality of downrange regions, for each downrange region, said controller configured to:

set a time delay for said programmable time delay;

set a gain for said programmable gain amplifier; and

trigger said transmit pulse generator.

41. The apparatus of Claim 36, wherein said light source is adapted for use as a turn-signal light.
42. The apparatus of Claim 41, wherein said light source comprises an incandescent light.
43. The apparatus of Claim 41, wherein said light source comprises an array of light emitting diodes.
44. The apparatus of Claim 36, wherein said light source is configured to operate as a reverse signal light.
- 5 45. The apparatus of Claim 44, wherein said light source comprises an incandescent light.
46. The apparatus of Claim 44, wherein said light source comprises an array of light emitting diodes.
47. A vehicle radar system comprising:  
a plurality of sensor units, each sensor unit comprising a radio frequency transmitter, a radio frequency receiver, a programmable time delay, a programmable gain amplifier, and a first network interface; and  
10 a controller unit, said controller unit comprising a second network interface configured to communicate with said first network interface using current-carrier networking.
48. The radar system of Claim 47, wherein said controller is further configured to use each of said sensor units to search downrange for targets within the field of view of that sensor unit.
49. The radar system of Claim 47, wherein said controller is further configured to obtain crossrange  
15 information by using each of said sensor units to search for targets within the field of view of that sensor unit.
50. The radar system of Claim 47, wherein said first network interface is addressable.
51. The radar system of Claim 47, wherein said plurality of sensor units comprises a first sensor unit and a second sensor unit, said first and second sensor units having a first and second field of view respectively, said first field of view being different from said second field of view.
- 20 52. The radar system of Claim 51, wherein a portion of said first field of view overlaps a portion of said second field of view.
53. The radar system of Claim 47 wherein said plurality of sensor units comprises a first sensor unit and a second sensor unit, said first and second sensor units mounted to a vehicle, said vehicle having left and right side-object regions, said first sensor unit having a field of view that substantially covers said left side-object region and said second  
25 sensor unit having a field of view that substantially covers said right side-object region.
54. The radar system of Claim 47 wherein said radar sensor unit is configured to be powered by a reverse light circuit.
55. The radar system of Claim 54, wherein at least a portion of each of said sensor units is powered by an alternating current carrier signal applied to said reverse light circuit, said carrier signal having insufficient voltage to cause  
30 said light to reach full brightness.
56. The radar system of Claim 47 wherein each of said sensor units is powered by a turn-signal circuit.
57. An integrated vehicle light source and radar sensor apparatus, comprising:  
a light source powered by a light circuit;  
a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy; and  
a network interface, said network interface configured to extract a first modulated carrier signal from  
said light circuit, said network interface configured to insert a second modulated carrier onto said light circuit.

58. The apparatus of Claim 57, further comprising:

5 a programmable time delay configured to select a selected portion of said pulses received by said  
radio frequency receiver;

a programmable gain amplifier configured to amplify said selected portion; and

10 a controller unit, said controller unit configured to program said programmable time delay and said  
programmable gain amplifier to detect targets with a field of view of said sensor at different downrange  
distances.

59. The radar sensor of Claim 57, wherein said controller unit is further configured to compute a velocity  
of said targets.

60. The radar sensor of Claim 57, wherein said network interface is an addressable interface.

61. The radar sensor of Claim 57, wherein said sensor supplies information about said targets to a central  
15 controller.

62. The radar sensor of Claim 61, wherein said central controller supplies information about said targets  
to an airbag deployment system.

63. The radar sensor of Claim 61, wherein said controller supplies information about said targets to other  
vehicle systems connected to an information bus.

20 64. The radar sensor of Claim 57, wherein said sensor uses time division multiple access.

65. The radar sensor of Claim 57, wherein said sensor uses code division multiple access.

66. The radar sensor of Claim 57, further comprising a fault sensor to detect an operating condition of said  
light source.

67. The radar sensor of Claim 66, wherein said fault sensor comprises a current sensor.

25 68. The radar sensor of Claim 66, wherein said fault sensor comprises a voltage sensor.

69. The radar sensor of Claim 66, wherein said fault sensor comprises an optical sensor.

70. The radar sensor of Claim 57, further comprising a truck, said sensor mounted on said truck.

71. The radar sensor of Claim 57, further comprising a semi-trailer, said sensor mounted on said semi-  
trailer.

30 72. The radar sensor of Claim 57, further configured to track and discriminate multiple Doppler shifted  
targets in crossrange and downrange.

73. An audible warning device comprising:

a network interface; and

a sound producing device connected to said network interface and configured to accept commands from said network interface.

74. The audible warning device of Claim 73, wherein said sound producing device is configured to project a first audible warning sound in response to a first command and a second audible warning sound in response to a second command.

75. The audible warning device of Claim 73, wherein said audible warning device is configured to receive power and network data signals from a reverse light circuit.

76. The audible warning device of Claim 73, wherein said audible warning device is configured to project a first audible warning sound when no command has been received by said network interface and a second audible warning sound in response to a command received by said network interface.

77. The audible warning device of Claim 73, wherein said audible warning device is mounted to the rear of a vehicle such that said first audible warning sound and said second audible warning sound are projected into an area generally behind said vehicle.

78. The audible warning device of Claim 73, wherein said audible warning device is mounted in a passenger compartment of a vehicle.

79. An integrated vehicle light source and sensor apparatus, comprising:

a light source powered by a first electrical circuit;

an electronic sensor;

a network interface, said network interface configured to extract a first modulated carrier signal from a second electrical circuit, said network interface configured to insert a second modulated carrier onto said second electrical circuit.

80. The apparatus of Claim 79, wherein said electronic sensor comprises a radar sensor.

81. The apparatus of Claim 79, wherein said electronic sensor comprises a fault sensor to sense an operating condition of said light source.

82. The apparatus of Claim 79, wherein said electronic sensor comprises a switch to operate said light source.

83. The apparatus of Claim 79, wherein said electronic sensor comprises an ultrasonic sensor.

84. The apparatus of Claim 79, wherein said first electrical circuit and said second electrical circuit are connected together as a single electrical circuit.

85. The apparatus of Claim 84, wherein said electronic sensor comprises a switch to operate said light source.

86. An automotive radar comprising:

a radio frequency oscillator;

a transmit pulse generator;



a transmit antenna;

a transmit switch, said transmit switch configured to connect said oscillator to said transmit antenna, said transmit switch operated by an output of said transmit pulse generator;

a receive antenna configured to provide received signals to a downconverter operatively coupled to a filter, and output of said filter being an analog intermediate frequency signal;

a programmable time delay;

a programmable gain amplifier;

a digital data system, said digital data system configured to convert said analog intermediate frequency signal into a digital intermediate frequency signal in response to said programmable time delay; and

a controller operably connected to said transmit pulse generator, said programmable time delay, and said programmable gain amplifier, said controller configured to search for targets at a plurality of downrange regions, for each downrange region, said controller configured to:

set a time delay for said programmable time delay;

set a gain for said programmable gain amplifier; and

collect a plurality of said digital intermediate frequency signals corresponding to a target range determined by said programmable time delay.

87. The automotive radar of Claim 86, further comprising a visual display configured to display downrange information about targets detected by said radar.

88. The automotive radar of Claim 87, wherein said visual display is configured to display information about the target which is closest to said radar.

89. The automotive radar of Claim 87, wherein said visual display is configured to display information about targets with a shortest time to impact to said radar.

90. A radar system capable of tracking and discriminating multiple Doppler shifted targets, said radar system comprising:

a plurality of sensor units, each sensor unit comprising a radio frequency transmitter, a radio frequency receiver, a programmable time delay, a programmable gain amplifier, and a digital-to-analog converter, said digital-to-analog converter configured to convert an analog intermediate frequency signal into a digital intermediate frequency signal in response to said programmable time delay; and

a controller unit, said controller unit operably connected to each of said sensor units such that said controller unit can program said programmable time delay and said programmable gain amplifier.

91. The radar system of Claim 90 wherein said controller is further configured to use each of said sensor units to search downrange for targets within the field of view of that sensor unit.

92. The radar system of Claim 90 wherein said controller is further configured to obtain crossrange information by using at least two of said sensor units to search for targets within the field of view of that sensor unit.

93. The radar system of Claim 90 wherein said plurality of sensor units comprises a first sensor unit, a second sensor unit, and a third sensor unit, said first, second and third sensor units mounted to the rear of a vehicle such that at least said first, second, and third sensor unit has a field of view which extends behind said vehicle, said first sensor unit mounted near the centerline of said vehicle, said second sensor unit mounted to the left of said first sensor unit and said third sensor unit mounted to the right of said first sensor unit.

94. The radar system of Claim 90 wherein said plurality of sensor units comprises at least first and second sensor units, said first and second sensor units having a first and second field of view respectively, said first field of view being different from said second field of view.

95. The radar system of Claim 94 wherein a portion of said first field of view overlaps a portion of said second field of view.

96. The radar system of Claim 90 wherein said plurality of sensor units comprises at least first and second sensor units, said first and second sensor units mounted to a vehicle, said vehicle having left and right side-object regions, said first sensor unit having field of view that substantially covers said left side-object region and said second sensor unit having a field of view that substantially covers said right side-object region.

97. The radar system of Claim 90 wherein said controller unit is configured to be operably connectable to a vehicle power circuit.

98. The radar system of Claim 97 wherein each of said sensor units is configured to be operably connectable to a vehicle power circuit.

99. The radar system of Claim 97 wherein said vehicle power circuit carries radar data and data from other vehicle sensors.

100. The radar system of Claim 97 wherein said controller unit receives vehicle speed information from a vehicle information bus.

101. The radar system of Claim 97 wherein said controller unit receives vehicle speed information from a speedometer pick-up.

102. The radar system of Claim 97 wherein said controller unit receives vehicle speed information from a speed-sensing radar unit.

103. The radar system of Claim 97 wherein said system categorizes a target into at least one of a plurality of categories according to speed of the vehicle and distance to the target.

104. The radar system of Claim 97 wherein said system categorizes a target into at least one of a plurality of categories according to a distance to said target and a relative speed between said target and a vehicle carrying said radar system.

105. The radar system of Claim 104 wherein said system provides a first warning for targets in a first category and a second warning for targets in a second category.

106. A method searching for targets to provide downrange information from a pulsed radar system, comprising the steps of:

selecting a range gate;

programming a time delay of a programmable time delay based on said range gate;

programming a gain of a programmable gain amplifier based on said range gate;

transmitting a pulse of radio frequency energy;

receiving reflections of said pulse of radio frequency energy, said reflections produced by said pulse of radio frequency energy being reflected off of target objects;

downconverting at least some of said reflections to produce an analog intermediate frequency (IF) signal;

amplifying said analog IF signal to produce an amplified analog IF signal; and

converting said amplified analog IF signal into a digital IF signal in response to said range gate.

107. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said radar sensor comprising:

a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy, said receiver configured to convert said pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter configured to convert said intermediate frequency signal into a stream of digital samples in response to a programmable time delay; and

a controller unit, said controller unit configured to program said programmable time delay to detect targets with a field of view of said sensor at different downrange distances.

108. The radar sensor of Claim 107, wherein said controller unit is further configured to compute a velocity of said targets.

109. The radar sensor of Claim 107, wherein said controller unit is further configured to compute an acceleration of said targets.

110. The radar sensor of Claim 107, wherein said sensor is connected to a information bus.

111. The radar sensor of Claim 110, wherein said sensor supplies information about said targets to an intelligent display connected to said information bus.

112. The radar sensor of Claim 110, wherein said sensor supplies information about said targets to an airbag deployment system.

113. The radar sensor of Claim 110, wherein said sensor supplies information about said targets to other vehicle systems connected to said information bus.

114. The radar sensor of Claim 107 further comprising a digital signal processor.

115. The radar sensor of Claim 107, further comprising a user interface.

116. The radar sensor of Claim 107, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a target having a second downrange distance.

5 117. The radar sensor of Claim 107, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a closest target having a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a closest target having a second downrange distance.

10 118. The radar sensor of Claim 107, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first velocity, said warning signal projecting a second sound when said radar sensor detects a target having a second velocity.

15 119. The radar sensor of Claim 107, further comprising a visual warning device configured to project a visual warning signal, said visual warning signal projecting a first warning when said radar sensor detects a target having a first velocity, said visual warning signal projecting a second warning when said radar sensor detects a target having a second velocity.

120. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said radar sensor comprising:

radio frequency transmitter means for transmitting pulses of radio frequency energy;

20 radio frequency receiver means for receiving reflected pulses of radio frequency energy and converting said reflected pulses of radio frequency energy into an intermediate frequency signal;

digital to analog converter means for converting said intermediate frequency signal into a stream of digital samples in response to a programmable time delay; and

controller means for programming said programmable time delay to detect targets with a field of view of said sensor at different downrange distances.

25 121. A lane-change aid system for providing information to a driver of a vehicle about objects in a side-object region, said system comprising:

a radar sensor unit configured to provide radar target information to a user interface; and

a speedometer pick-up configured to provide vehicle speed information to said user interface.

30 122. The lane change aid system of Claim 121, wherein said radar sensor unit comprises:

a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy, said receiver configured to convert said pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter configured to convert said intermediate frequency signal into a stream of digital samples in response to a programmable time delay; and

a controller unit, said controller unit configured to program said programmable time delay to detect targets with a field of view of said sensor at different downrange distances.

123. The lane-change aid system of Claim 121, wherein said user interface does not warn said driver about objects detected by said radar sensor beyond a maximum range when said vehicle is moving at less than a desired speed.

5 124. The lane-change aid system of Claim 121, wherein said user interface does not audibly warn said driver about objects detected by said radar sensor beyond a range of about five feet when said vehicle is traveling less than about 15 miles per hour.

125. The lane-change aid system of Claim 121, wherein said radar sensors are intelligent radar sensor, each intelligent radar sensor comprising a control unit configured to transmit radar target information on an information bus.

10 126. The lane-change aid system of Claim 121, wherein said user interface comprises a visual indicator.

127. The lane-change aid system of Claim 121, wherein said user interface comprises an audible warning and a visual warning.

128. The lane-change aid system of Claim 121, wherein said user interface comprises an audible warning.

129. The lane-change aid system of Claim 128, wherein said user interface does not sound said audible  
15 warning when said vehicle is traveling at less than a desired speed.

130. The lane-change aid system of Claim 128, wherein said user interface sounds an audible warning according to a distance to a detected target and a relative speed between said vehicle and said detected target.

131. The lane-change aid system of Claim 121, further comprising a turn-signal pick-up.

132. The lane-change aid system of Claim 131, wherein said user interface does not audibly warn a driver  
20 of left-side targets unless said turn-signal pick-up indicates that a left-side turn-signal has been activated.

133. The lane-change aid system of Claim 131, wherein said user interface does not audibly warn a driver of right-side targets unless said turn-signal pick-up indicates that a right-side turn-signal has been activated.

134. A method for warning a driver of a vehicle that a lane-change maneuver may result in a collision comprising the steps of:

25 sensing objects in a side-object region in response to activation of a turn-signal; and

visually warning said driver about said object;

measuring a velocity of said vehicle;

selecting a maximum range based on said velocity; and

audibly warning said driver if a range to said object is less than said maximum range.

30 135. A method for warning a driver of a vehicle that a lane-change maneuver may result in a collision comprising the steps of:

sensing objects in a side-object region in response to activation of a turn-signal; and

visually warning said driver about said object;

measuring a velocity of said object relative to a velocity of said vehicle;

selecting a maximum range based on said velocity of said object; and  
audibly warning said driver if a range to said object is less than said maximum range.

136. The method of Claim 135, wherein said step of measuring a velocity of said object comprises Doppler processing.

5 137. A lane-change aid system for providing information to a driver of a vehicle about objects in a side-object region, said system comprising:

user interface means for warning a driver of the possibility of an accident involving an object in an adjacent lane.

radar sensor means for providing radar target information to said user interface; and

10 speed sensing means for providing vehicle speed information to said user interface.

138. A pulse radar comprising:

a radio frequency oscillator;

a transmit pulse generator;

a transmit antenna;

15 a transmit switch, said transmit switch configured to connect said oscillator to said transmit antenna, said transmit switch operated by an output of said transmit pulse generator to transmit a radio-frequency pulse of energy, said radio-frequency pulse having a leading edge and a trailing edge; and

a receive antenna configured to provide received signals to a receiver, said receiver configured to measure a range to a target by calculating a time required for said radio frequency pulse to traverse a path from said transmit antenna, to said target, and then to said receive antenna, said receiver configured to calculate said time by detecting said trailing edge.

20 139. A method of using a pulse radar to search for targets and to measure a downrange distance to the targets, comprising the steps of:

transmitting a pulse of radio frequency energy, said pulse having a leading edge and a trailing edge;

25 receiving reflections of said pulse of radio frequency energy, said reflections produced by said pulse of radio frequency energy being reflected by target objects; and

measuring a time when said pulse is received by sensing said trailing edge.

140. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said radar sensor comprising:

30 a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy, said receiver configured to convert said pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter configured to convert said intermediate frequency signal into a stream of digital samples in response to a programmable time delay; and

a controller unit, said controller unit configured to program said programmable time delay to detect targets with a field of view of said sensor at different downrange distances, said distances measured according to a trailing edge of said pulses of radio frequency energy.

141. The radar sensor of Claim 140, wherein said controller unit is further configured to compute a velocity of said targets.

142. The radar sensor of Claim 140, wherein said controller unit is further configured to compute an acceleration of said targets.

143. The radar sensor of Claim 140, wherein said sensor is connected to a information bus.

144. The radar sensor of Claim 143, wherein said sensor supplies information about said targets to an airbag deployment system.

145. The radar sensor of Claim 140, further comprising a visual warning device configured to project a visual warning signal, said visual warning signal projecting a first warning when said radar sensor detects a target having a first velocity, said visual warning signal projecting a second warning when said radar sensor detects a target having a second velocity.

146. An array of light sources configured to be placed in a field of view of an antenna while still allowing the antenna to radiate and receive electromagnetic energy, comprising:

a first plurality of power supply lines, said power supply lines oriented orthogonal to an E-field produced by an antenna;

a second plurality of power supply lines, said power supply lines oriented orthogonal to an E-field produced by said antenna; and

a plurality of light sources, each source having a first terminal and a second terminal, said first terminal provided to at least one power supply line in said first plurality of power supply lines, said second terminal provided to at least one power supply line in said second plurality of power supply lines.

147. The array of Claim 146, further comprising a power supply bus, said power supply bus provided to each of said first plurality of power supply lines.

148. A method for transmitting electromagnetic energy through a plurality of light sources comprising the steps of:

providing a power supply conductor to each of said light sources; and

orienting a substantial portion of said power supply conductors orthogonal to an E-field of said electromagnetic energy.

149. A method for transmitting electromagnetic energy through a plurality of light sources comprising the steps of:

providing a conductor to power a light source in an array comprising a plurality of light sources; and

arranging said conductor to reduce electromagnetic coupling between said conductor and an E-field produced by an antenna disposed to radiate electromagnetic energy through said array.

150. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said sensor integrated into a vehicle taillight, said radar sensor comprising:

5 a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy, said receiver configured to convert said pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter configured to convert said intermediate frequency signal into a stream of digital samples in response to a programmable time delay;

10 a controller unit, said controller unit configured to program said programmable time delay to detect targets with a field of view of said sensor at different downrange distances; and

an array of light emitting diodes configured to operate as a vehicle taillight.

151. The radar sensor of Claim 150, wherein said controller unit is further configured to compute a velocity of said targets.

15 152. The radar sensor of Claim 150, wherein said controller unit is further configured to compute a distance to said targets by locating a trailing edge of received pulses.

153. The radar sensor of Claim 150, wherein said sensor is connected to a vehicle power circuit and said sensor is configured to provide a modulated carrier onto said vehicle power circuit.

20 154. The radar sensor of Claim 153, wherein said sensor supplies information about said targets to an intelligent display connected to said vehicle power circuit.

155. The radar sensor of Claim 153, wherein said sensor supplies information about said targets to an airbag deployment system.

156. The radar sensor of Claim 153, wherein said sensor supplies information about said targets to other vehicle systems connected to said vehicle power circuit.

25 157. The radar sensor of Claim 150 wherein said radio frequency transmitter is configured to transmit said pulses of radio frequency energy through said array of light emitting diodes.

158. The radar sensor of Claim 150, further comprising a user interface.

30 159. The radar sensor of Claim 150, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a target having a second downrange distance.

160. The radar sensor of Claim 150, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a closest target having



a first downrange distance, said warning signal projecting a second sound when said radar sensor detects a closest target having a second downrange distance.

161. The radar sensor of Claim 150, further comprising an audible warning device configured to project an audible warning signal, said warning signal projecting a first sound when said radar sensor detects a target having a first velocity, said warning signal projecting a second sound when said radar sensor detects a target having a second velocity.

162. The radar sensor of Claim 150, further comprising a visual warning device configured to project a visual warning signal, said visual warning signal projecting a first warning when said radar sensor detects a target having a first velocity, said visual warning signal projecting a second warning when said radar sensor detects a target having a second velocity.

163. A radar sensor capable of tracking and discriminating one or more Doppler shifted targets in downrange distance, said radar sensor comprising:

radar means for transmitting pulses of radio frequency energy and receiving reflected pulses of radio frequency energy and converting said reflected pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter for converting said intermediate frequency signal into a stream of digital samples in response to a programmable time delay;

controller means for programming said programmable time delay to detect targets with a field of view of said sensor at different downrange distances; and

lighting array means for signaling drivers of vehicles, said radar means configured to transmit and receive said pulses of radio frequency energy through said lighting means.

164. A lane-change aid system for providing information to a driver of a vehicle about objects in a side-object region, said system comprising:

a vehicle taillight array;

a radar sensor unit configured to provide radar target information to a user interface, said radar sensor unit disposed behind said array; and

a speedometer pick-up configured to provide vehicle speed information to said user interface.

165. The lane change aid system of Claim 164, wherein said radar sensor unit comprises:

a radio frequency transmitter configured to transmit pulses of radio frequency energy;

a radio frequency receiver configured to receive said pulses of radio frequency energy, said receiver configured to convert said pulses of radio frequency energy into an intermediate frequency signal;

a digital to analog converter configured to convert said intermediate frequency signal into a stream of digital samples in response to a programmable time delay; and

a controller unit, said controller unit configured to program said programmable time delay to detect targets with a field of view of said sensor at different downrange distances.

166. The lane-change aid system of Claim 165, wherein said user interface does not warn said driver about objects detected by said radar sensor beyond a maximum range when said vehicle is moving at less than a desired speed.

167. The lane-change aid system of Claim 165, wherein said user interface does not audibly warn said driver about objects detected by said radar sensor beyond a range of about five feet when said vehicle is traveling less than about 15 miles per hour.

168. The lane-change aid system of Claim 165, wherein said radar sensors are intelligent radar sensor, each intelligent radar sensor comprising a control unit configured to transmit radar target information on an information bus.

169. The lane-change aid system of Claim 165, wherein said user interface comprises a visual indicator.

170. The lane-change aid system of Claim 165, wherein said user interface comprises an audible warning and a visual warning.

171. The lane-change aid system of Claim 165, wherein said user interface comprises an audible warning.

172. The lane-change aid system of Claim 171, wherein said user interface does not sound said audible  
5 warning when said vehicle is traveling at less than a desired speed.

173. The lane-change aid system of Claim 171, wherein said user interface sounds an audible warning according to a distance to a detected target and a relative speed between said vehicle and said detected target.

174. The lane-change aid system of Claim 165, further comprising a turn-signal pick-up, said array and said transmitter activated in response to said turn signal pickup.

10 175. The lane-change aid system of Claim 174, wherein said user interface does not audibly warn a driver of left-side targets unless said turn-signal pick-up indicates that a left-side turn-signal has been activated.

176. The lane-change aid system of Claim 164, wherein said user interface does not audibly warn a driver of right-side targets unless said turn-signal pick-up indicates that a right-side turn-signal has been activated.

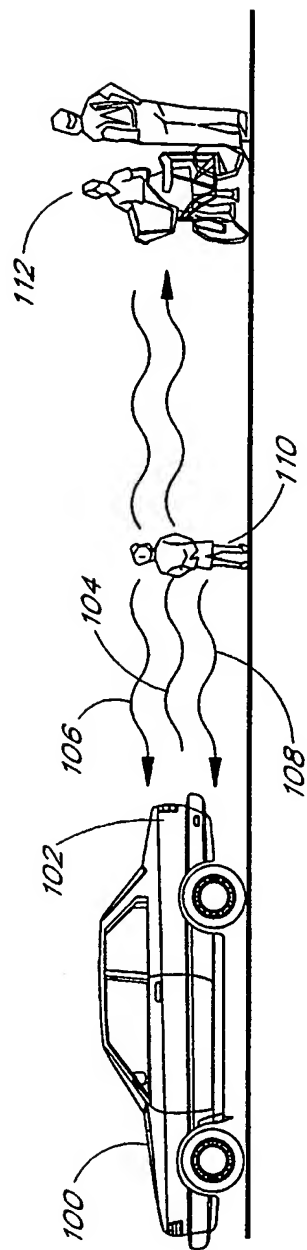
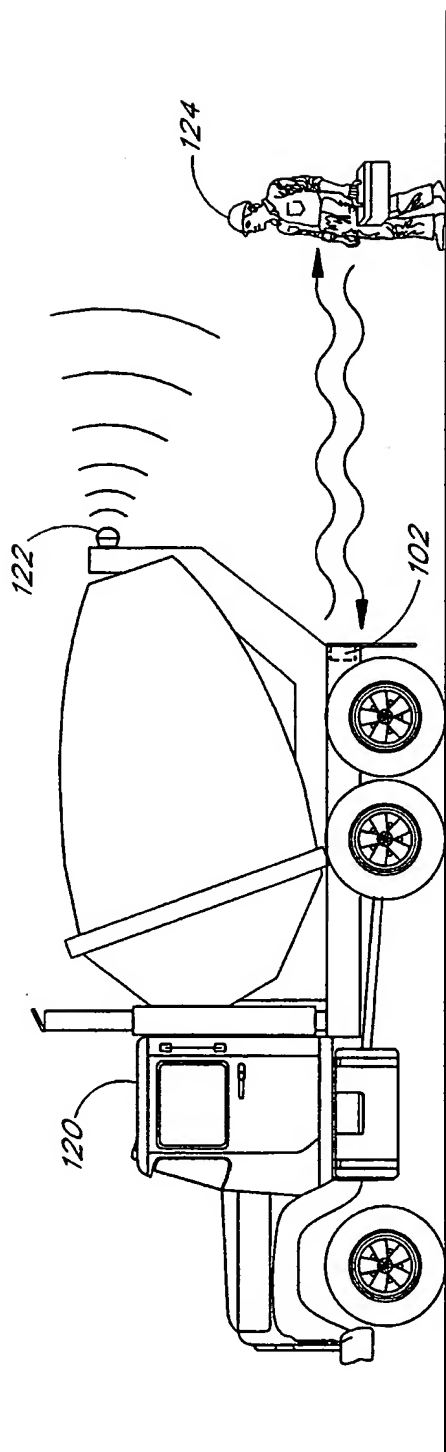


FIG. 1A

*FIG. 1B*

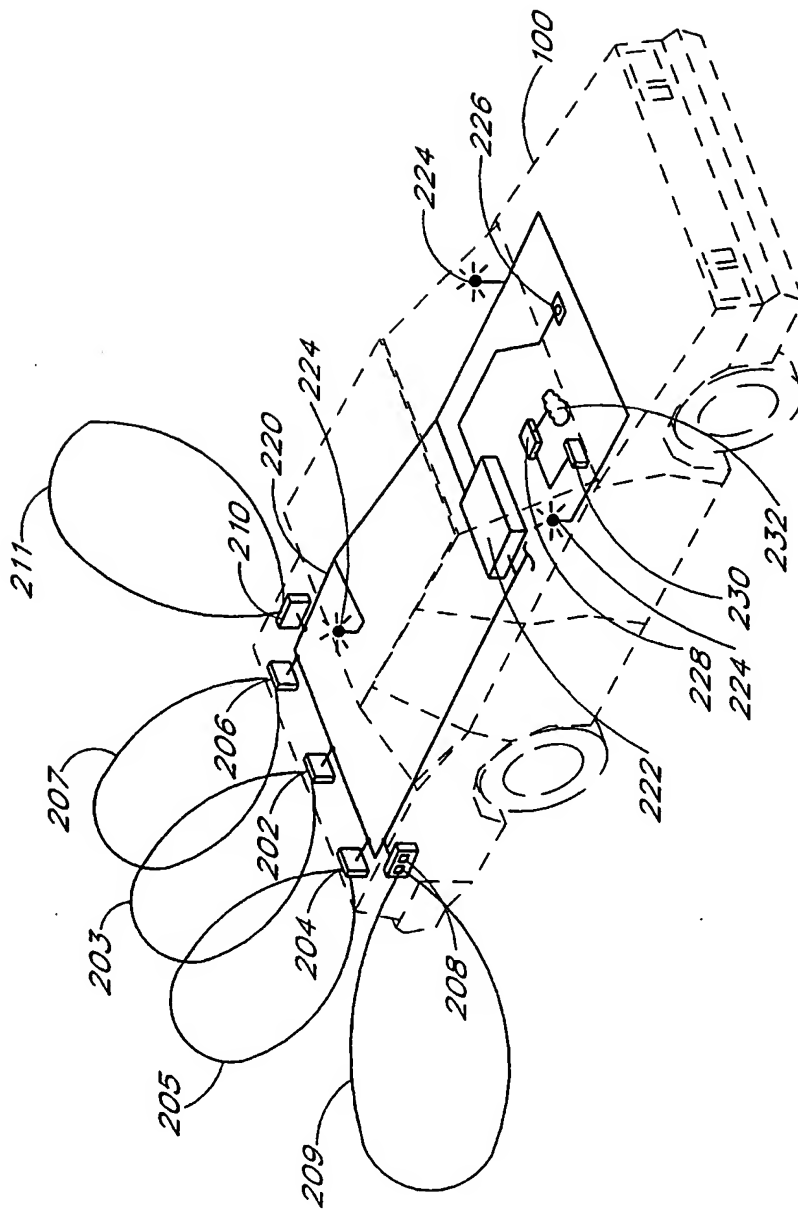
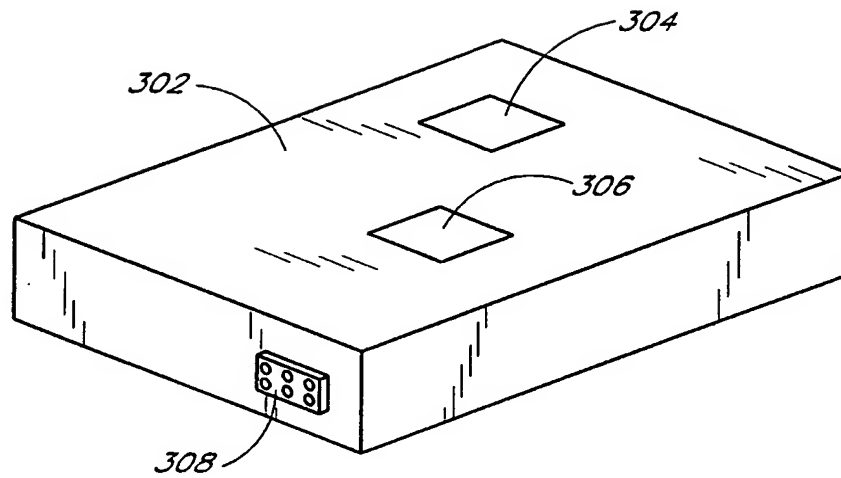
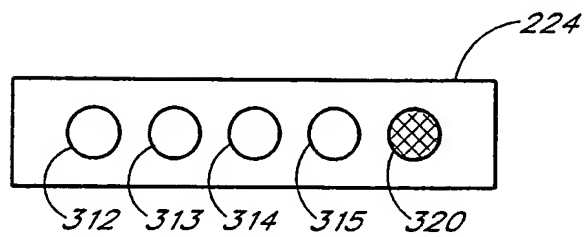


FIG. 2

*FIG. 3A**FIG. 3B*

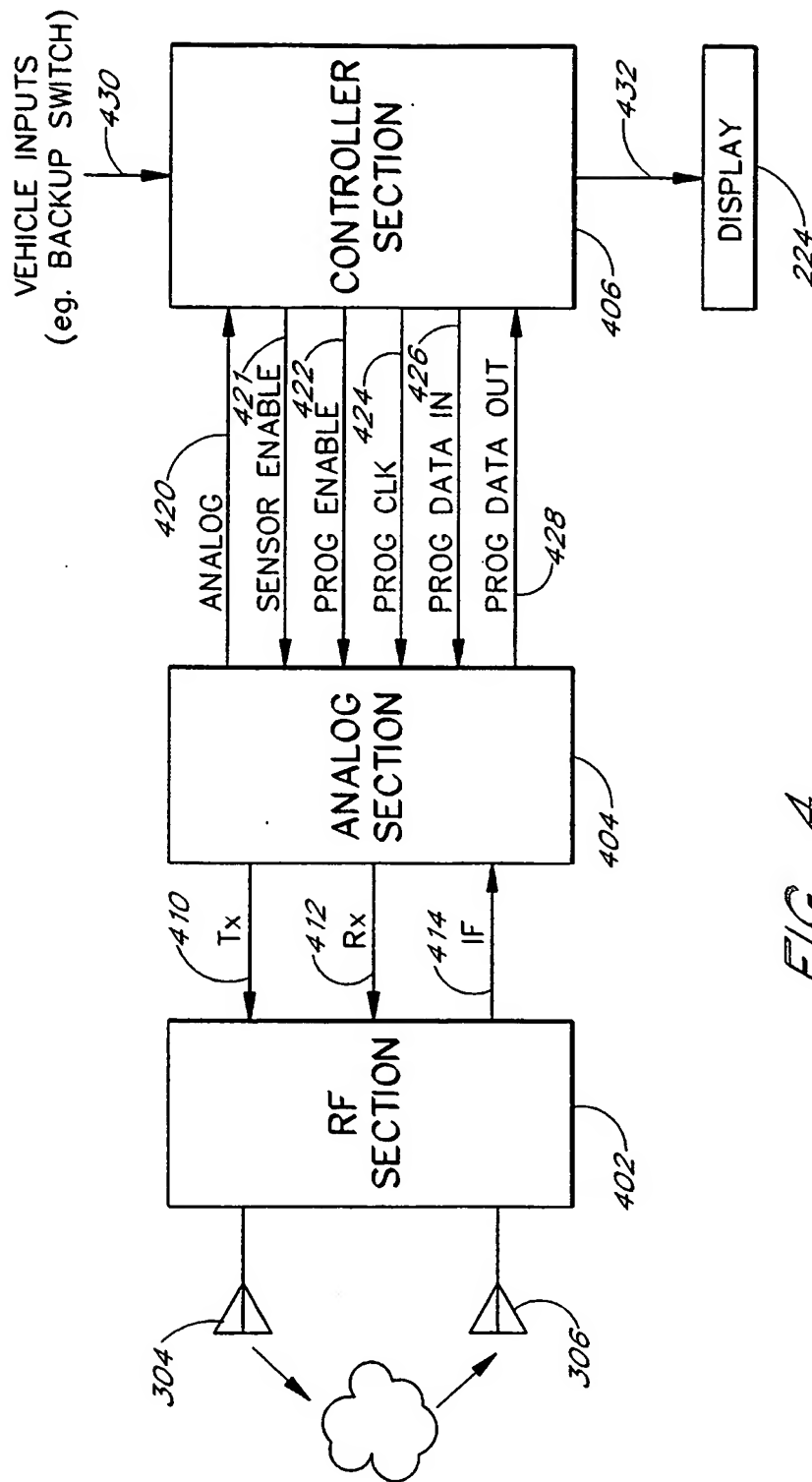


FIG. 4



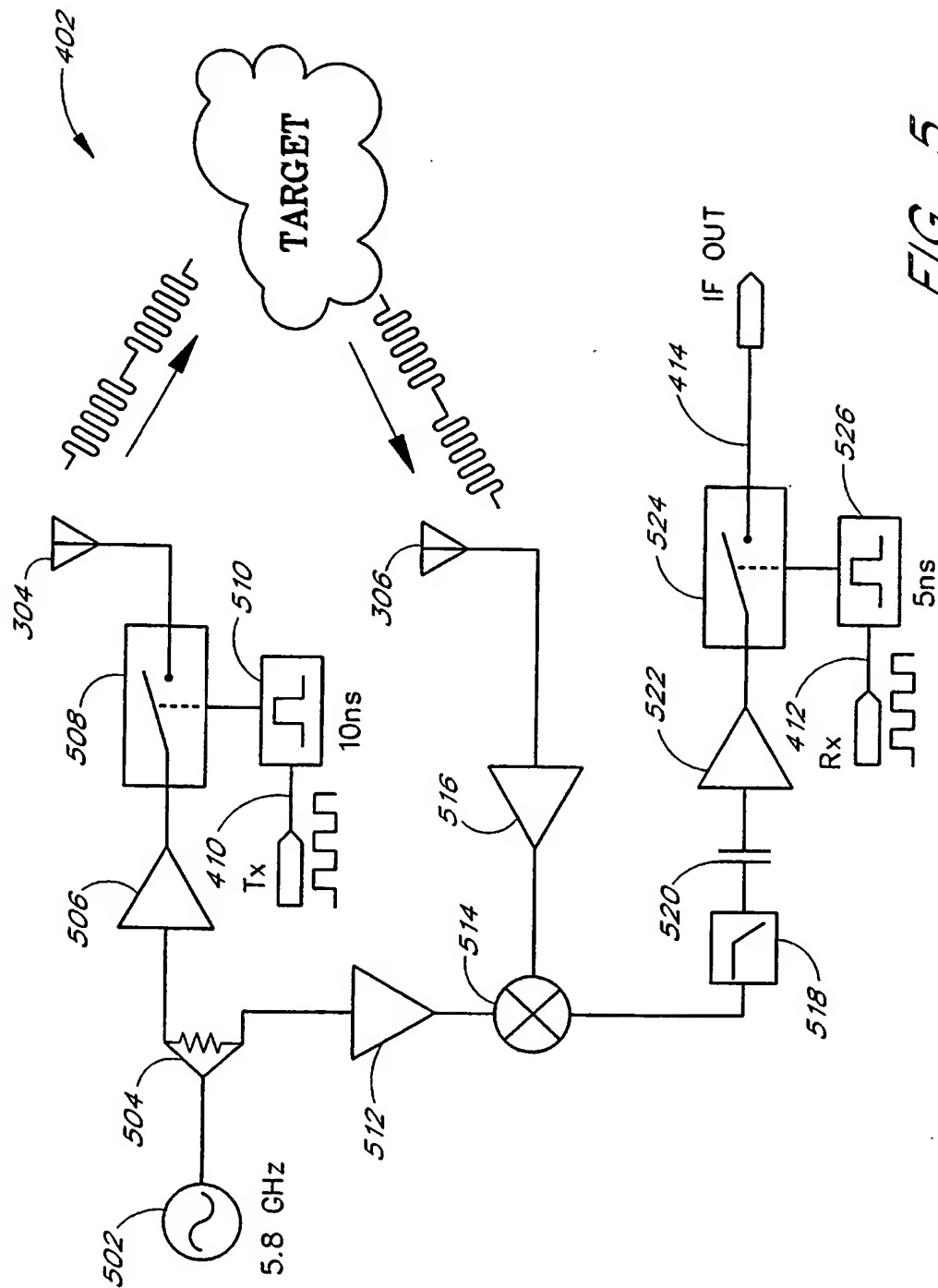


FIG. 5

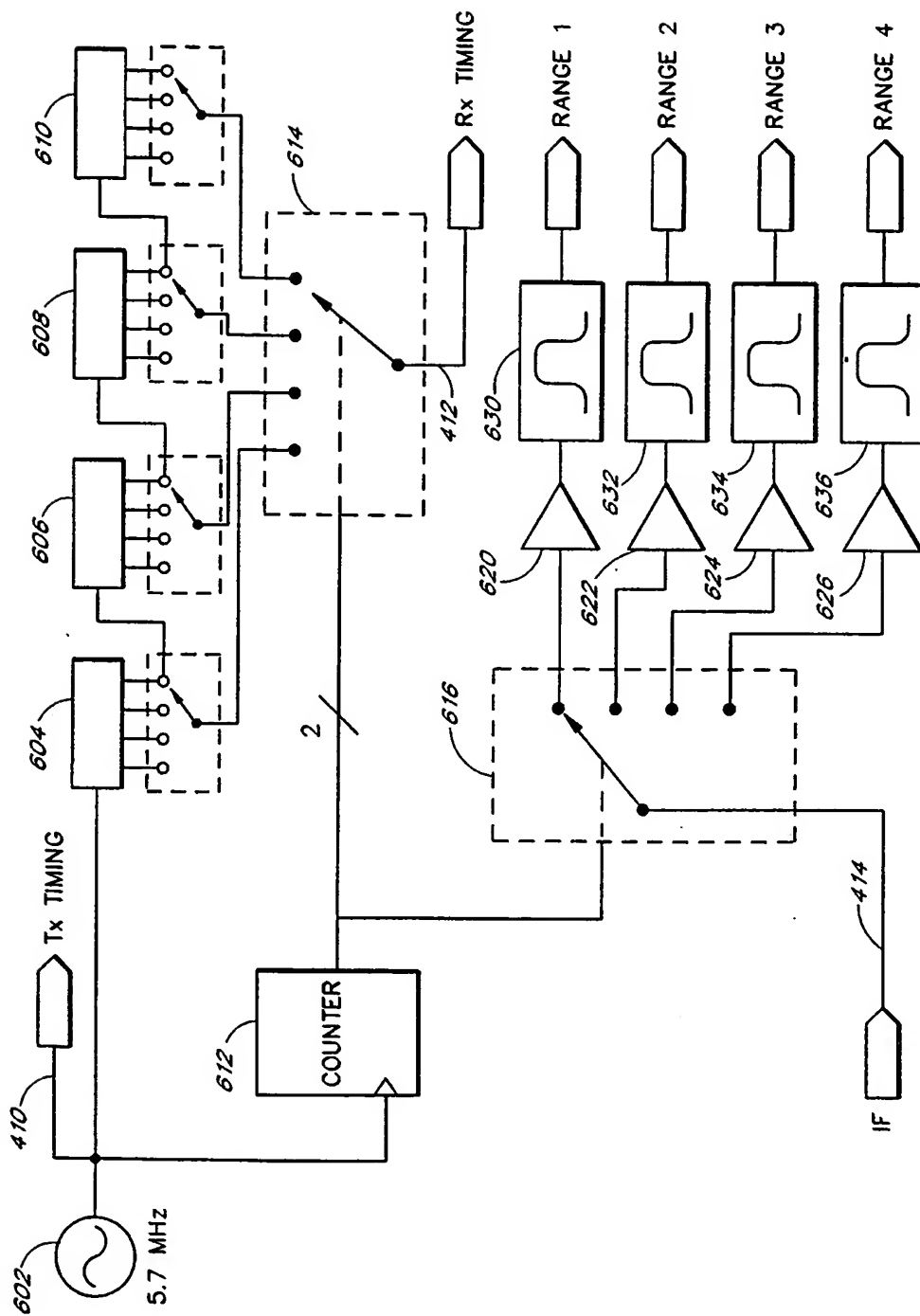


FIG. 6A

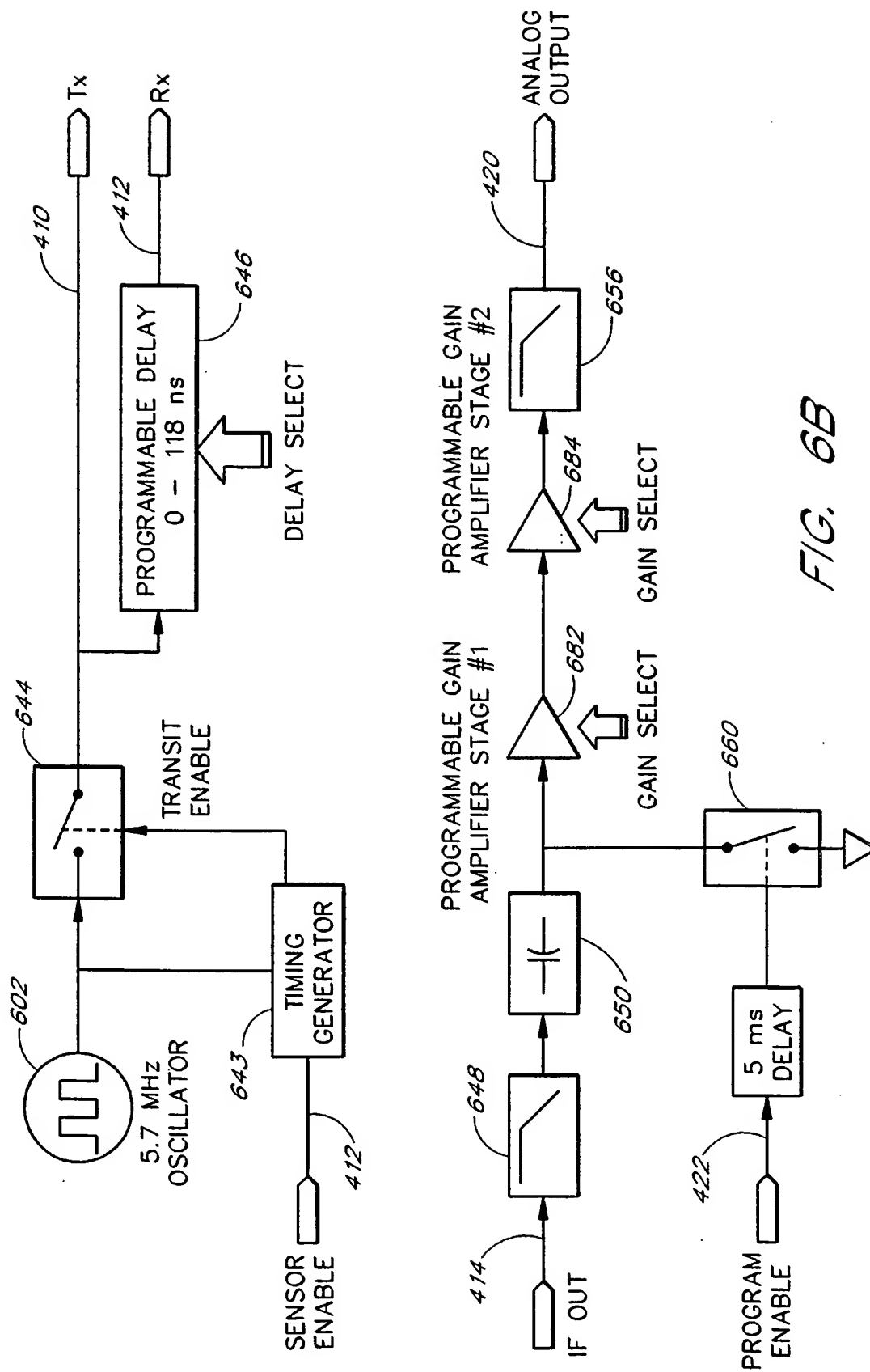


FIG. 6B

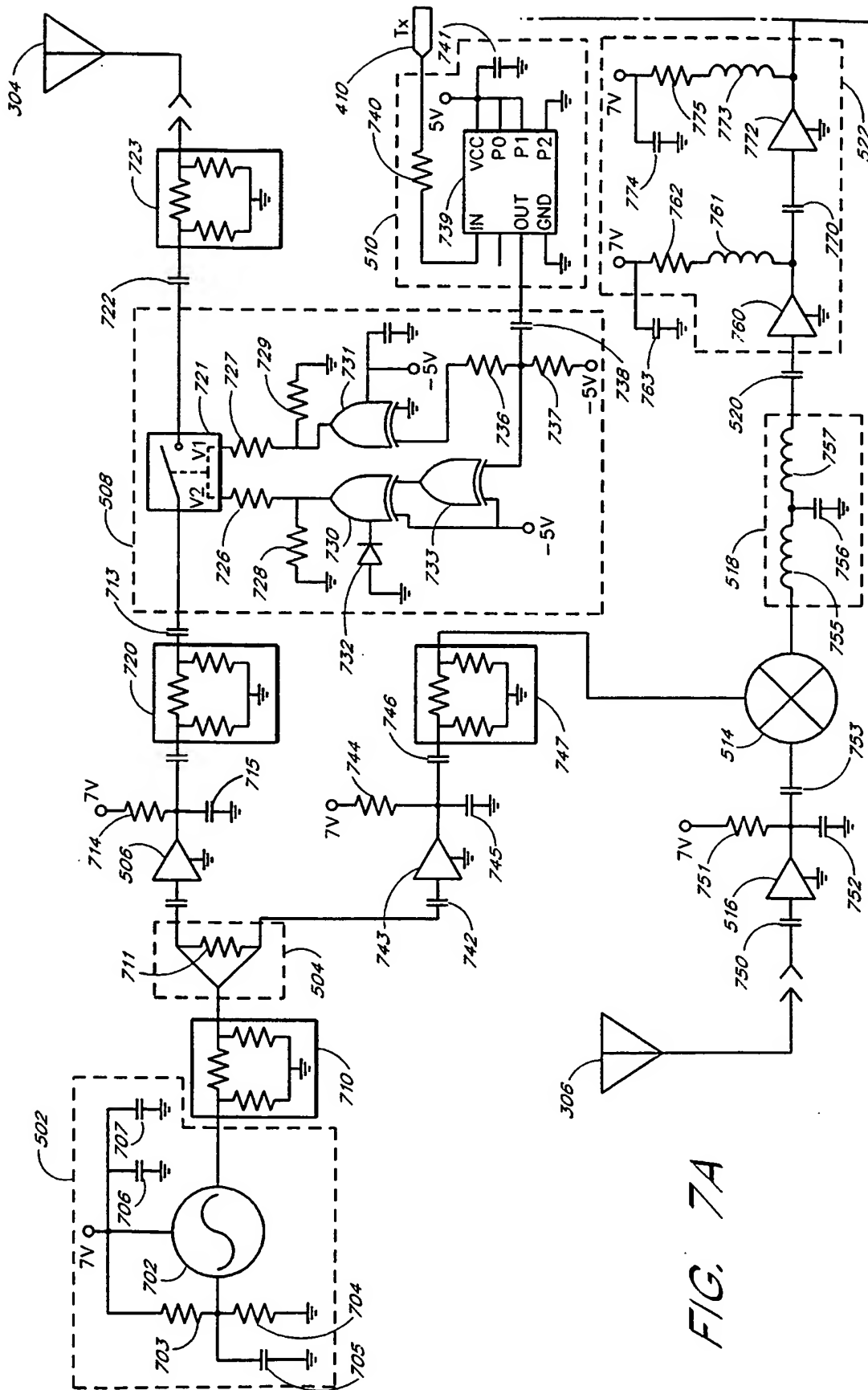


FIG. 7A

FIG. 7A	FIG. 7B
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FIG. 7

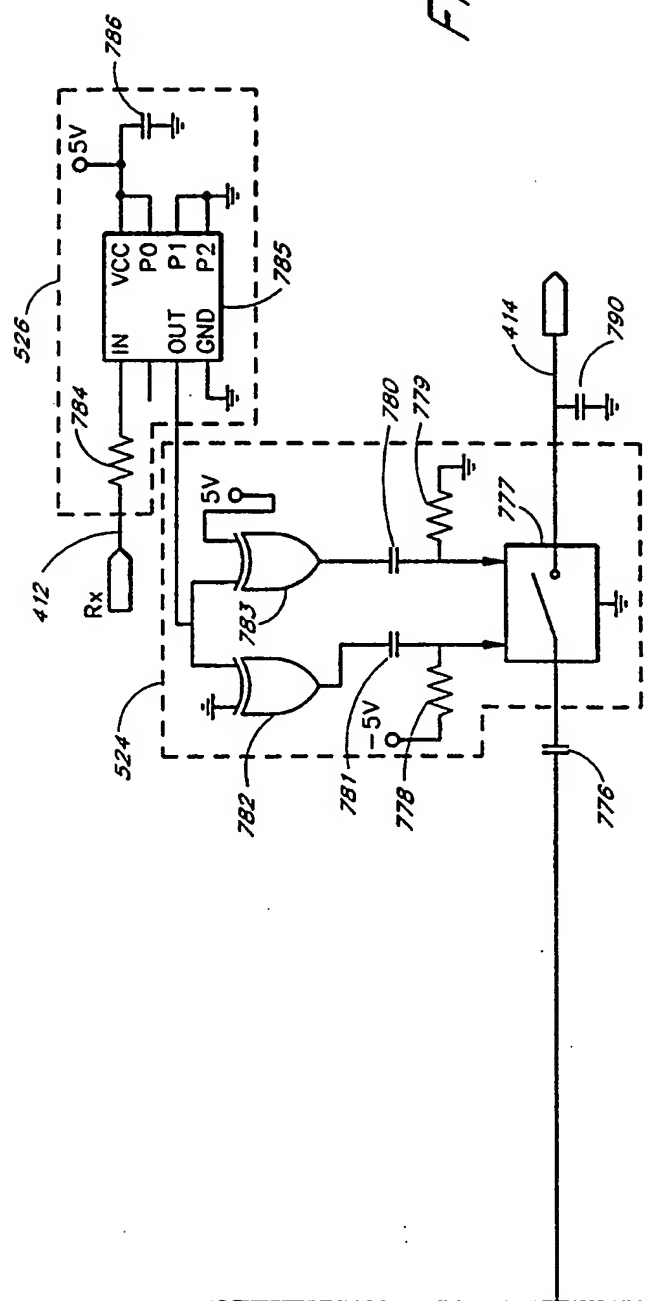


FIG. 7B



FIG. 8A	FIG. 8B
FIG. 8C	FIG. 8D

FIG. 8

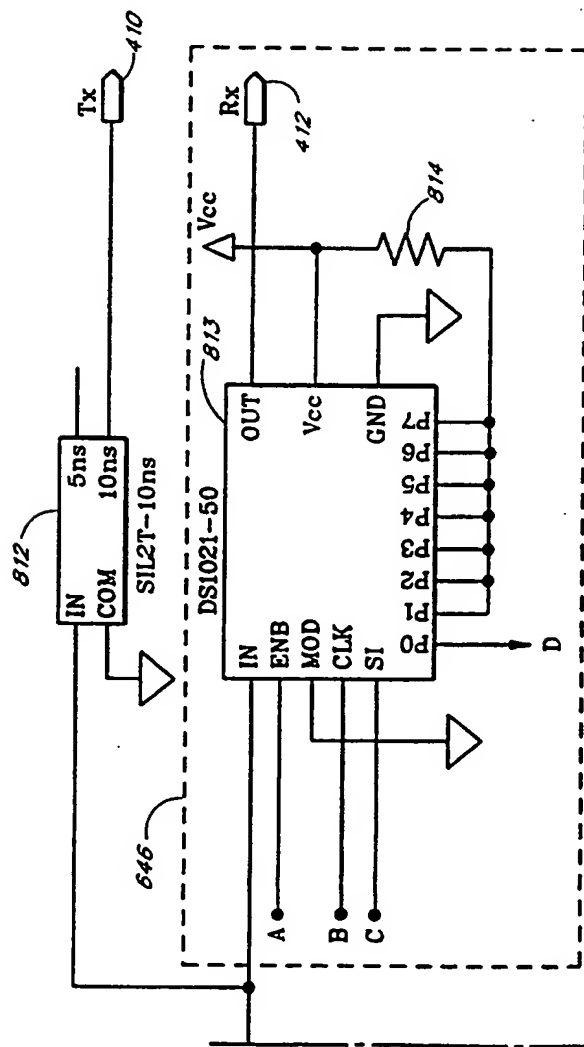


FIG. 8B

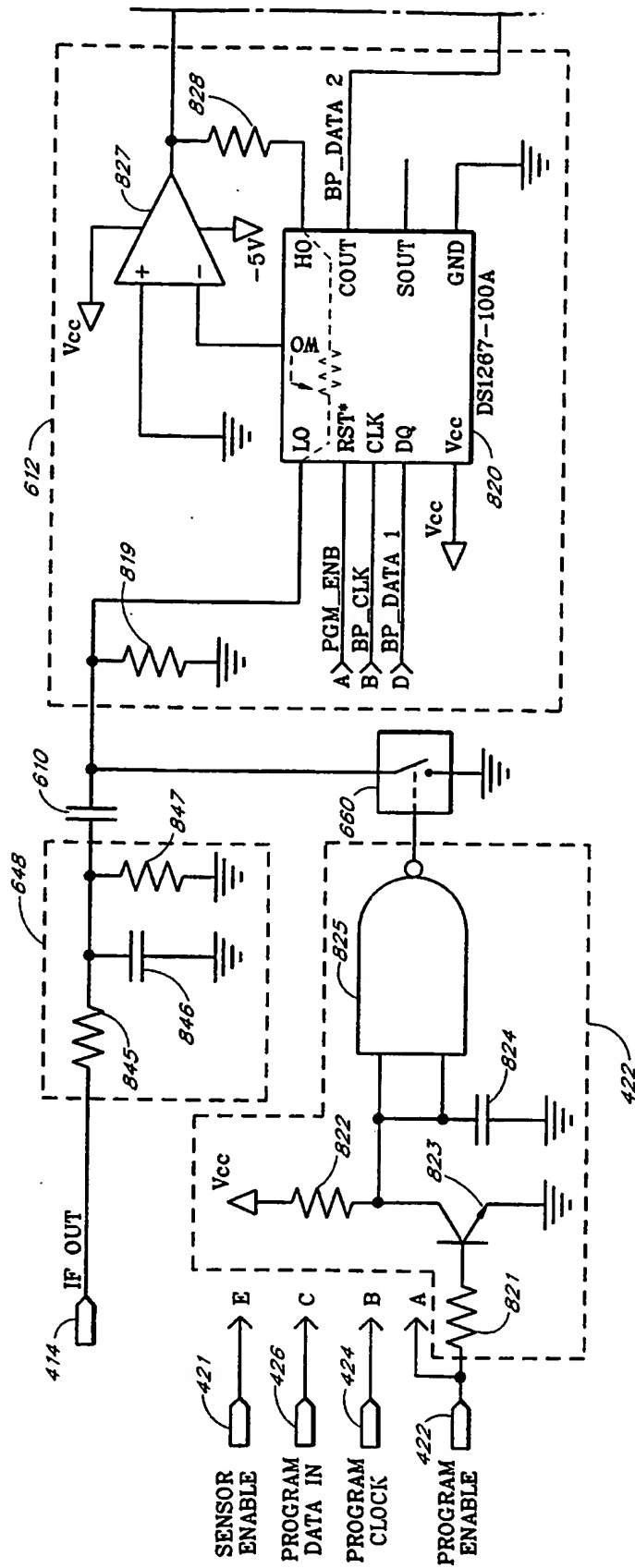


FIG. 8C



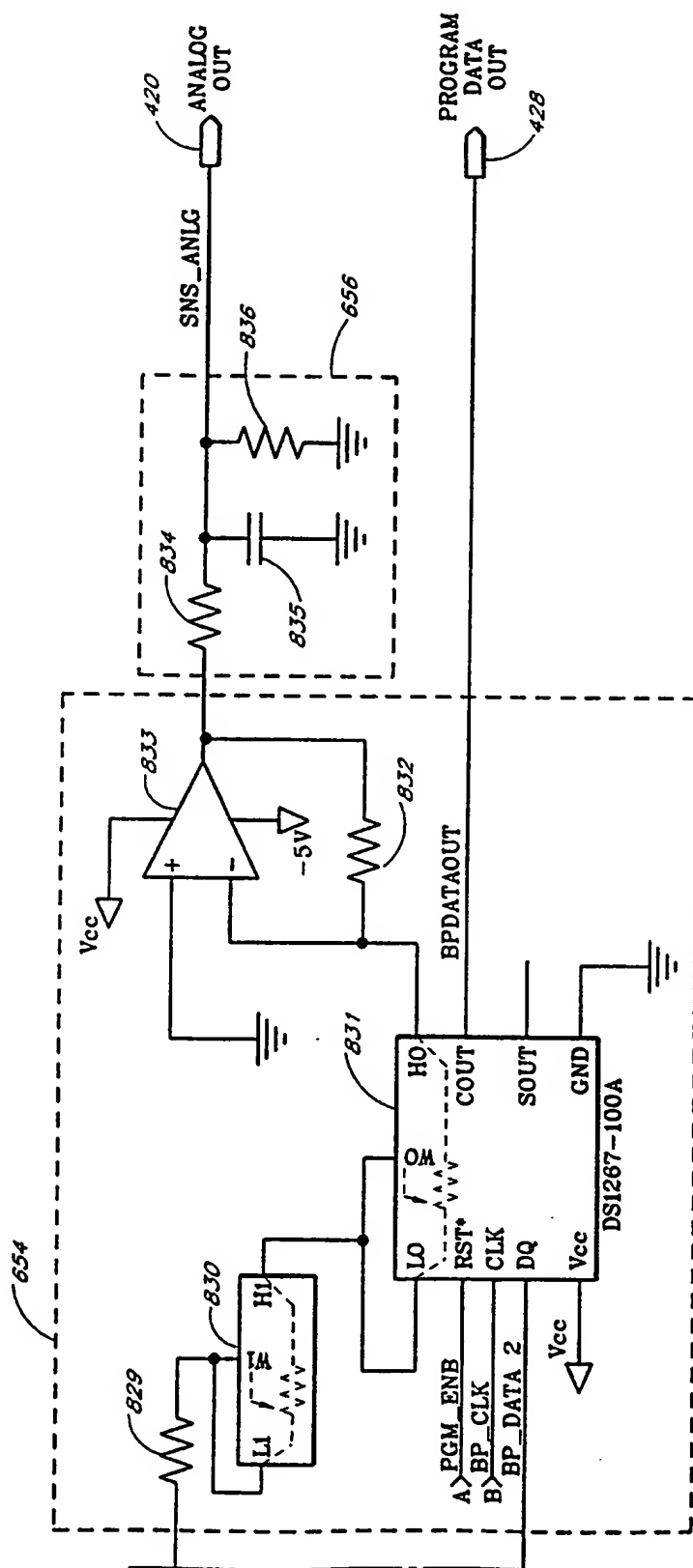
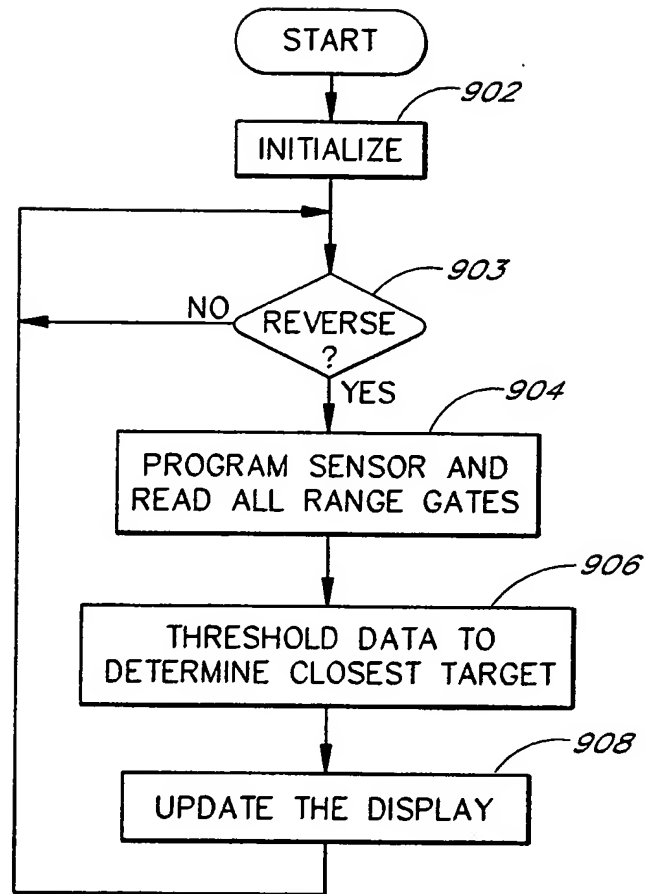


FIG. 8D

*FIG. 9*

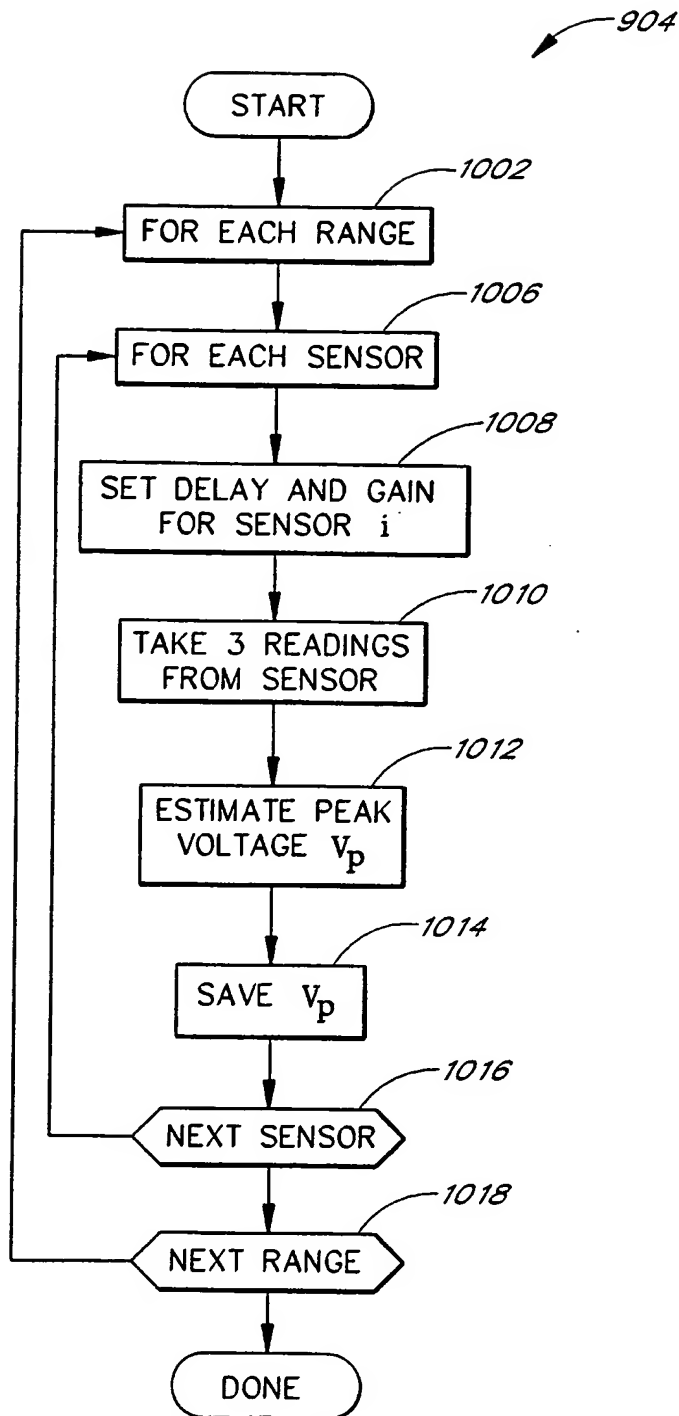


FIG. 10

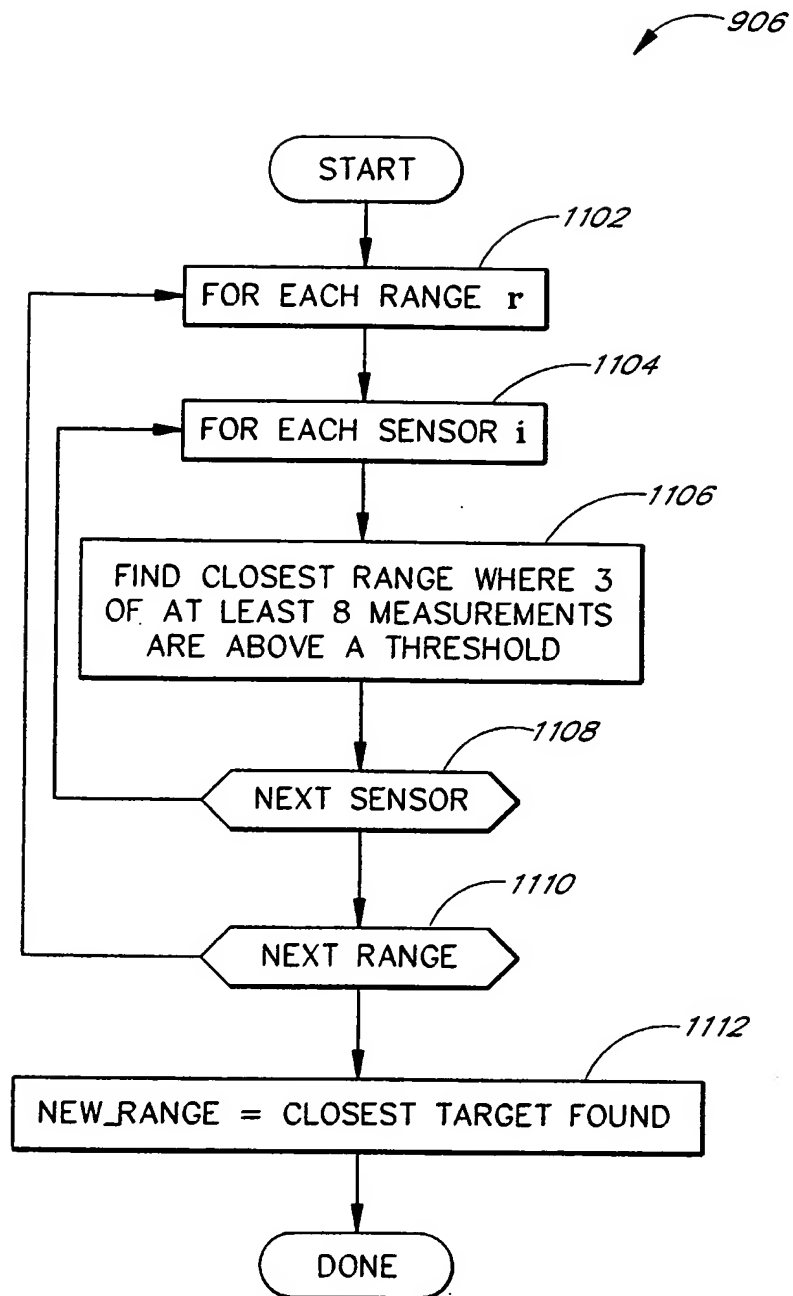


FIG. 11

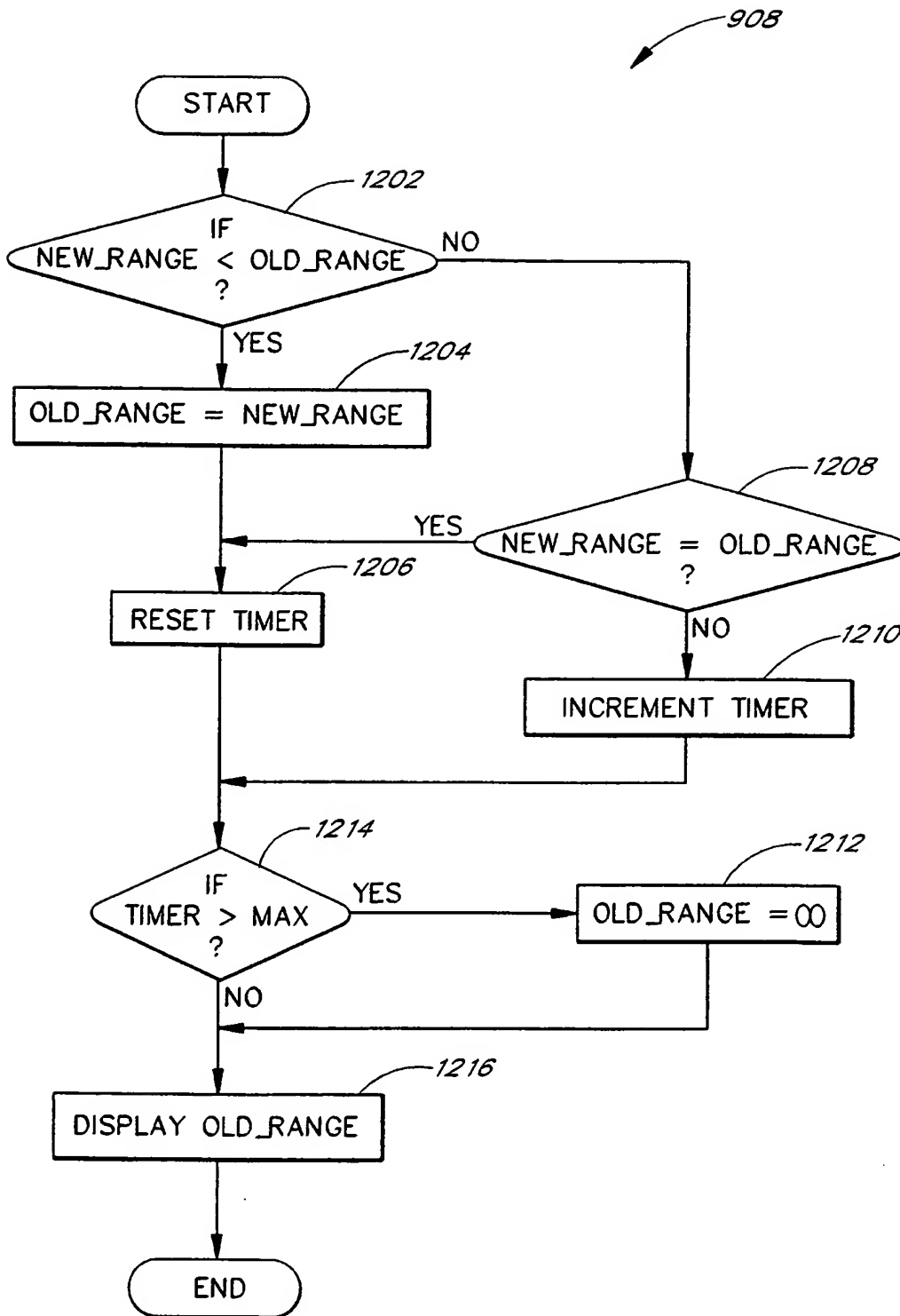
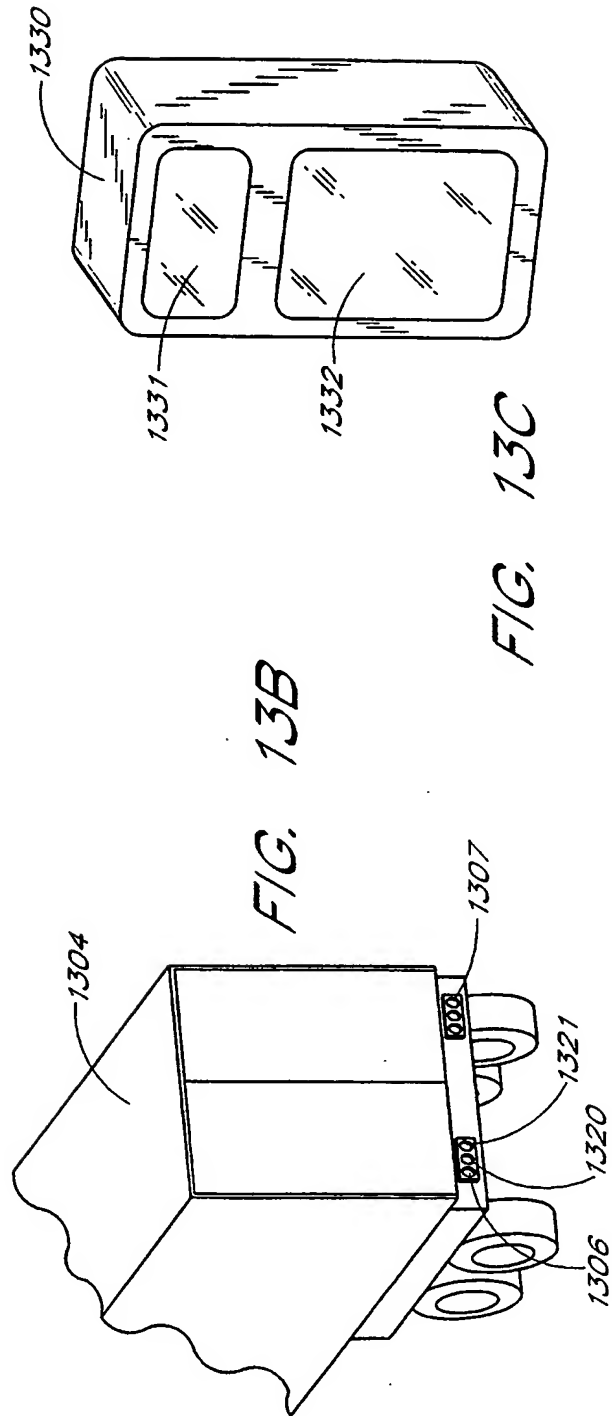
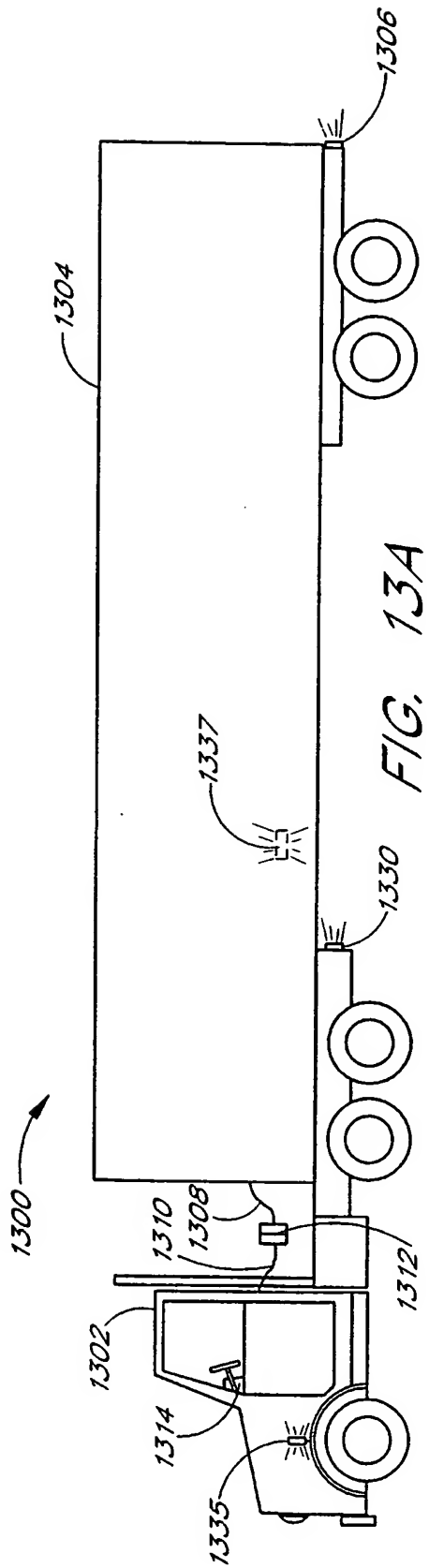
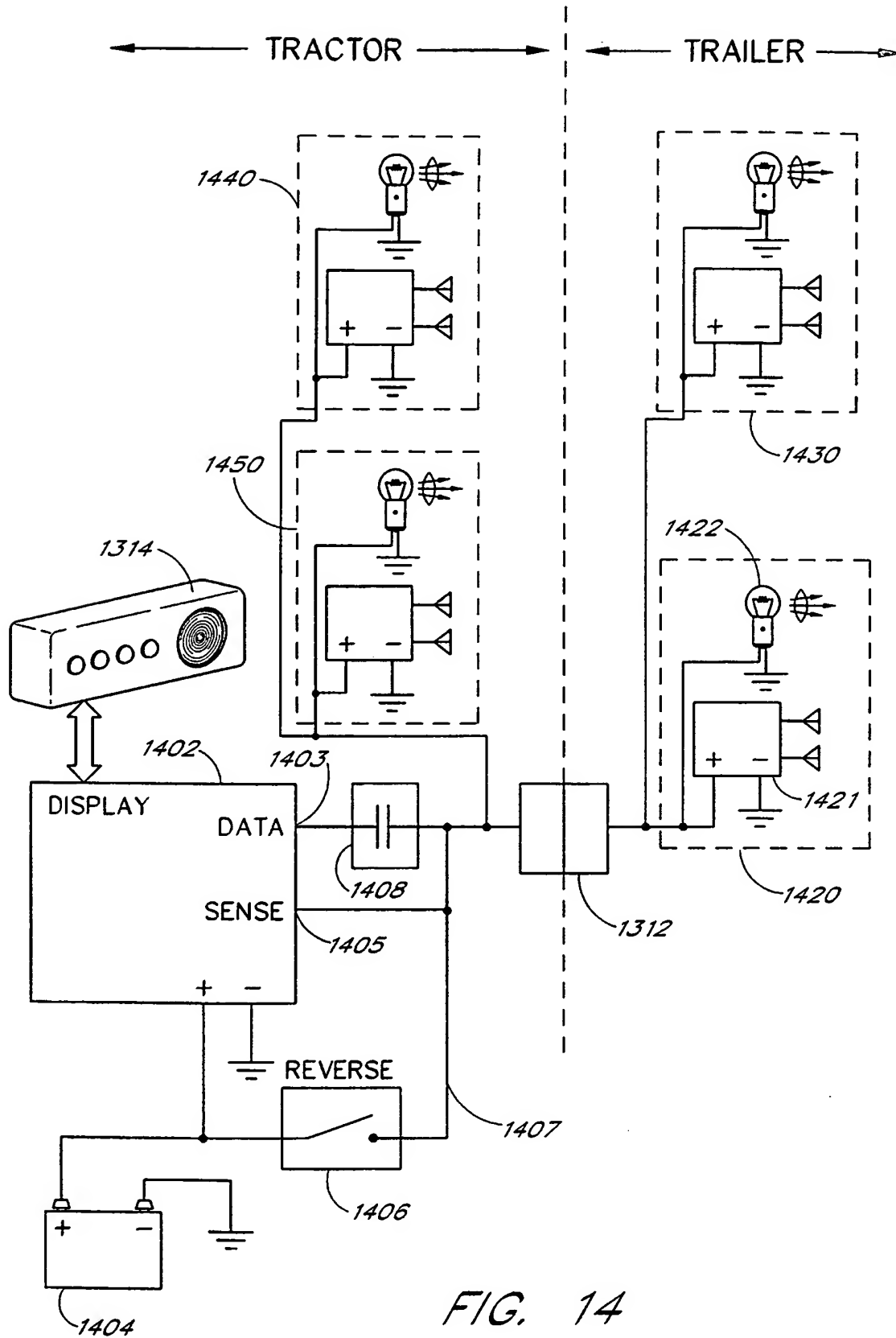


FIG. 12





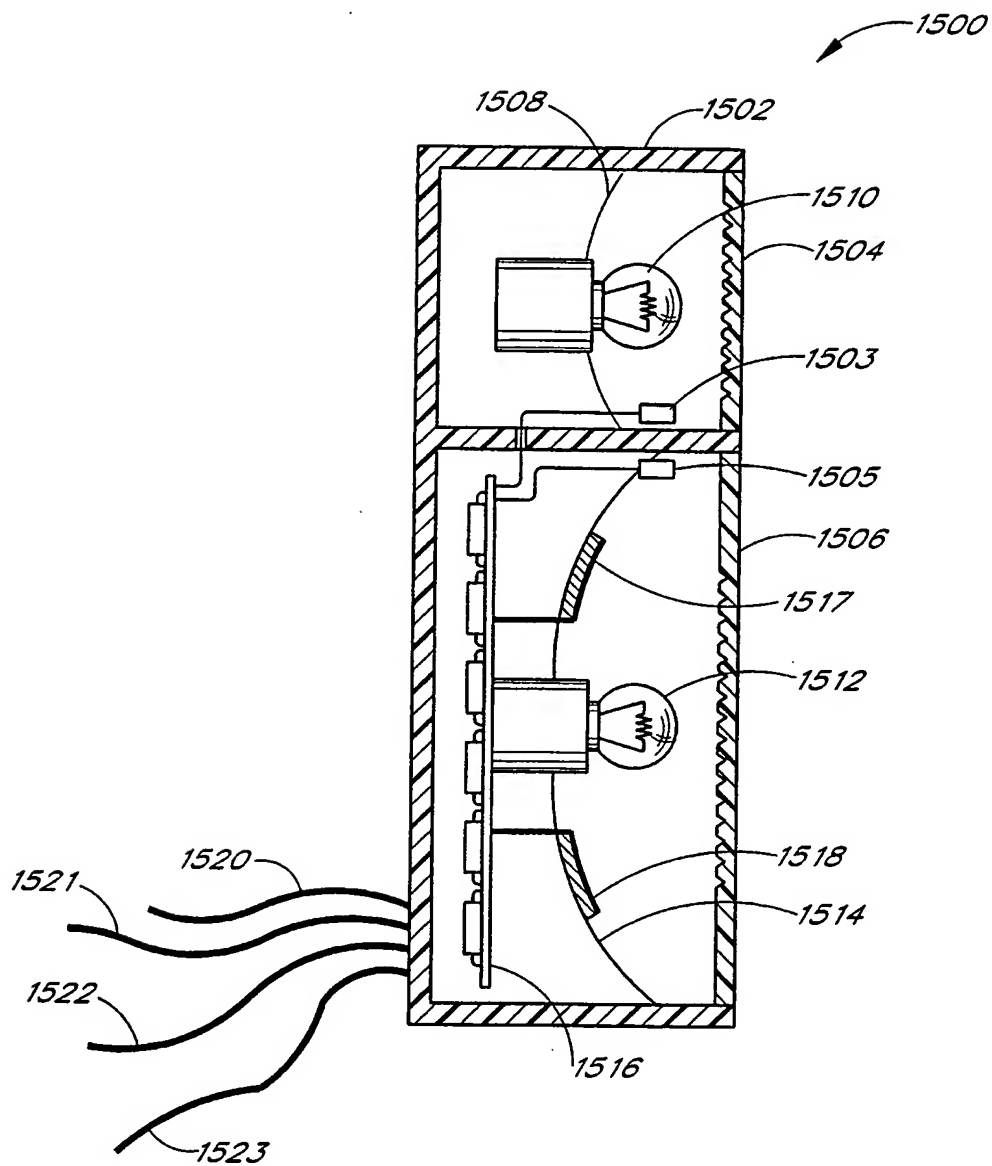
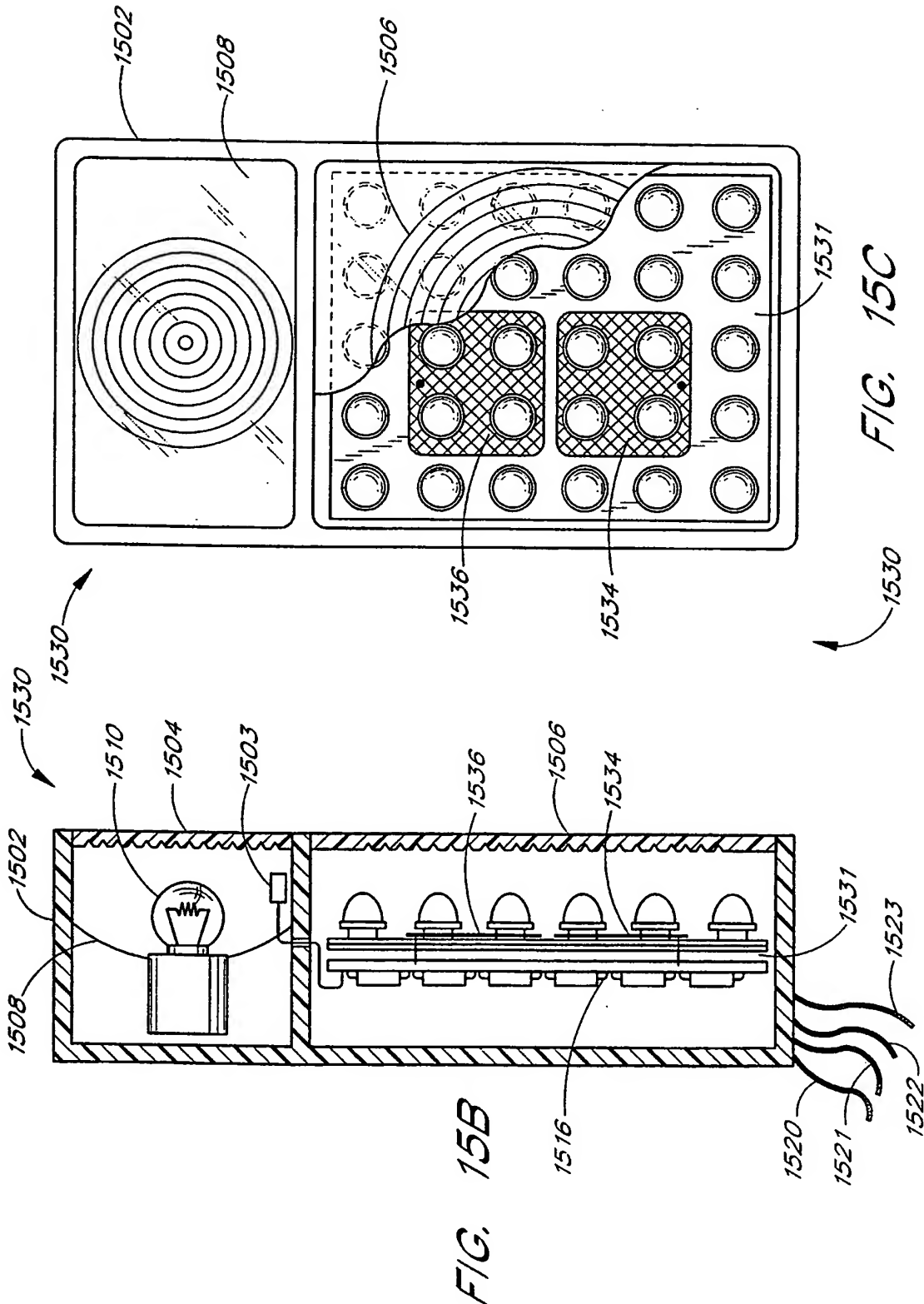


FIG. 15A





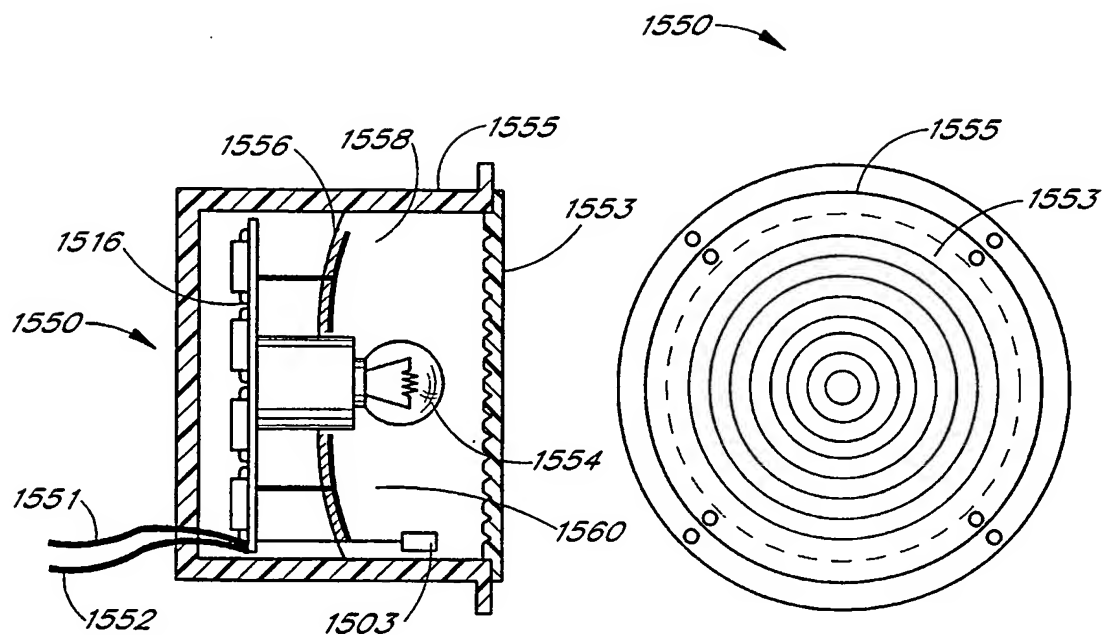


FIG. 15D

FIG. 15E

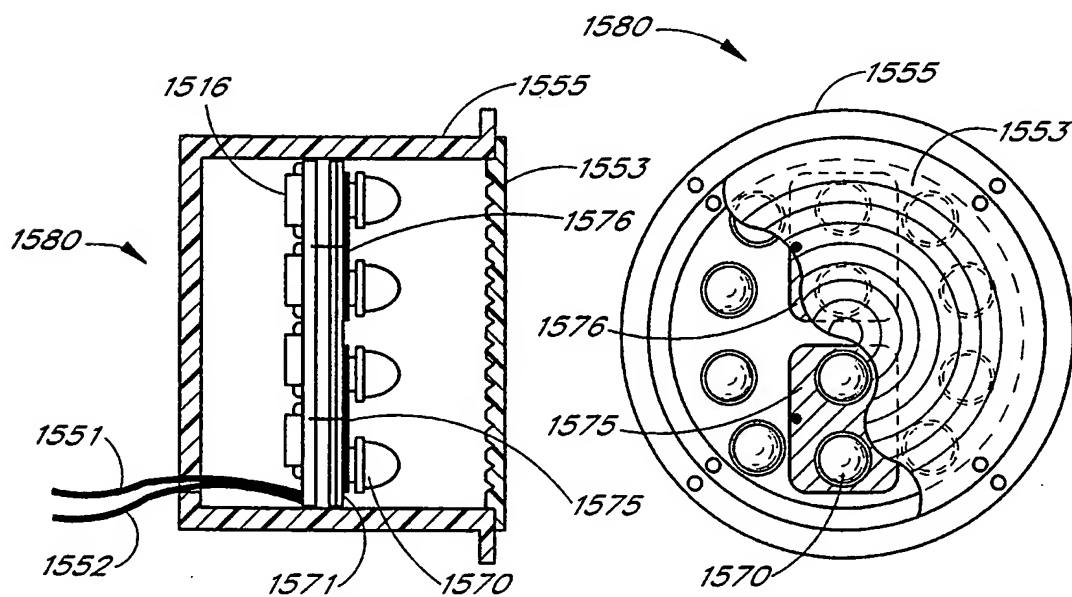
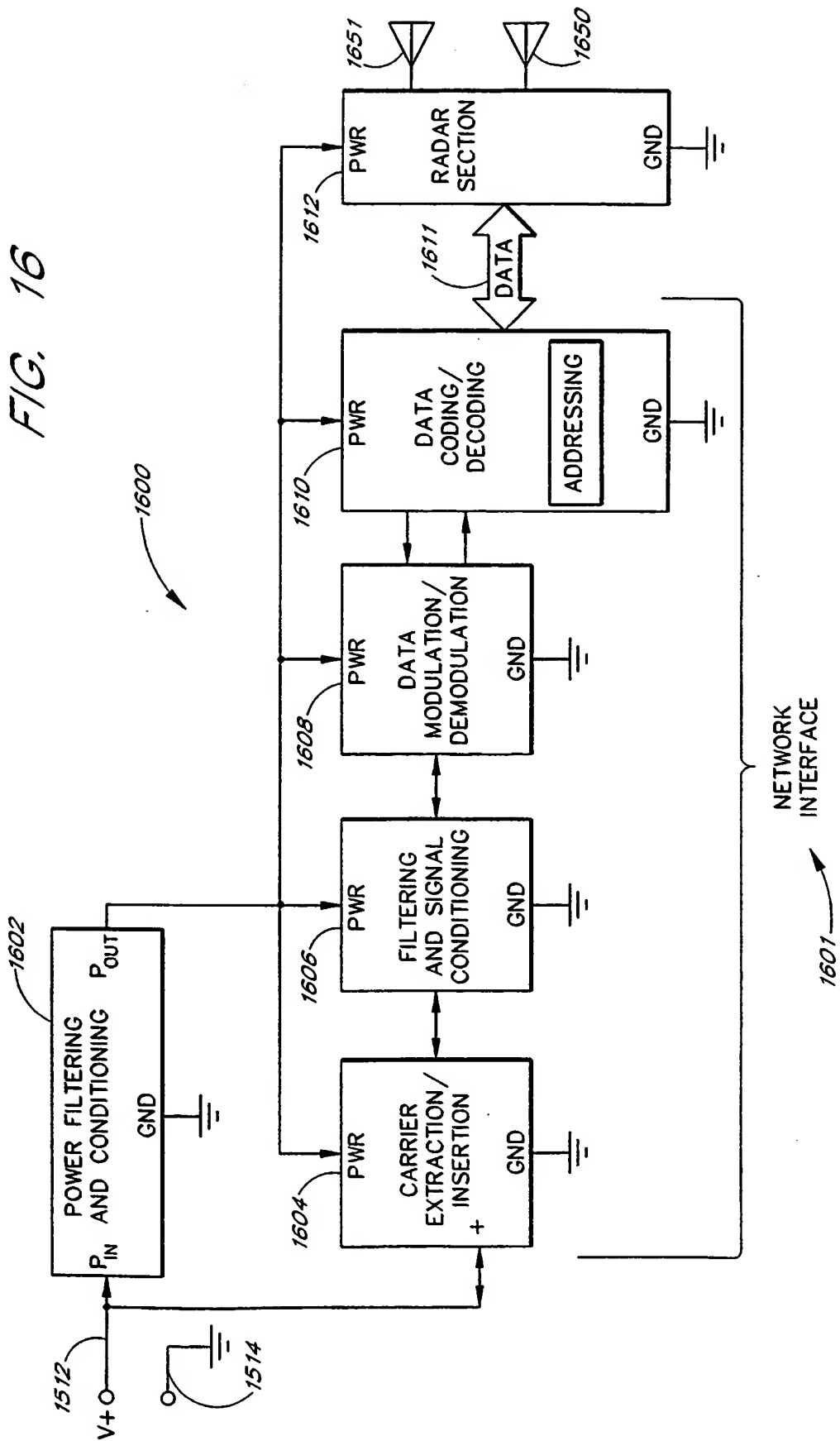
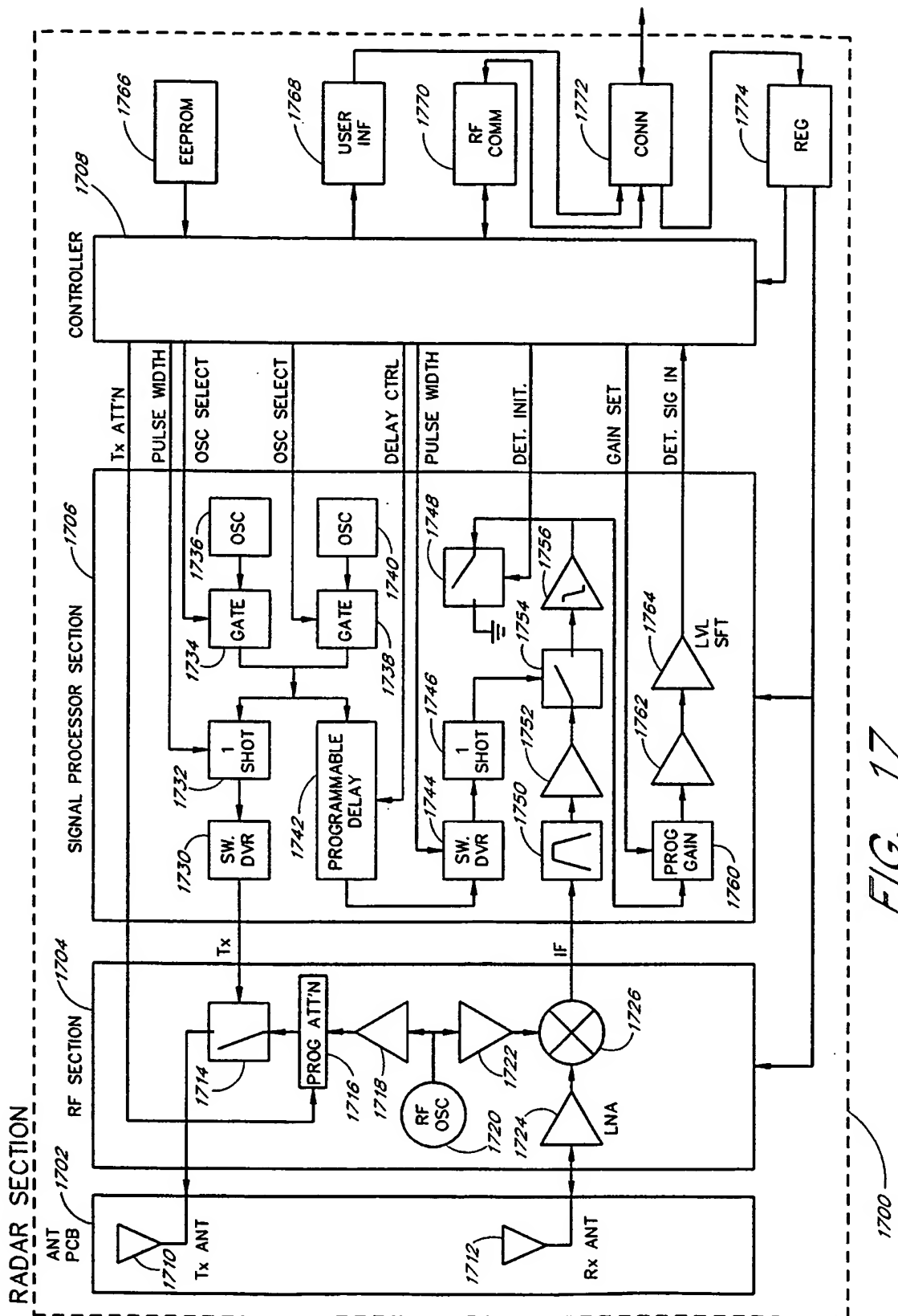


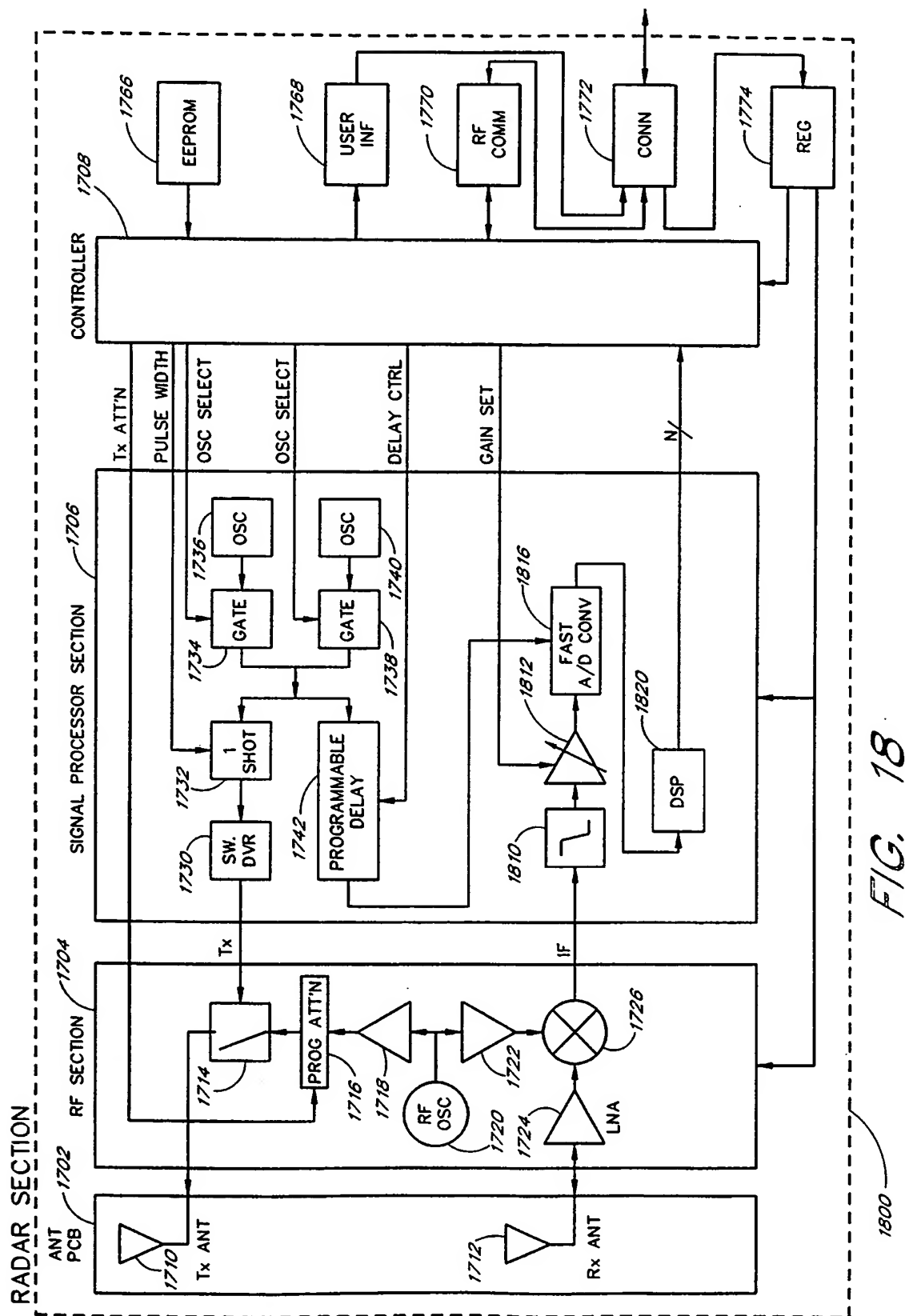
FIG. 15F

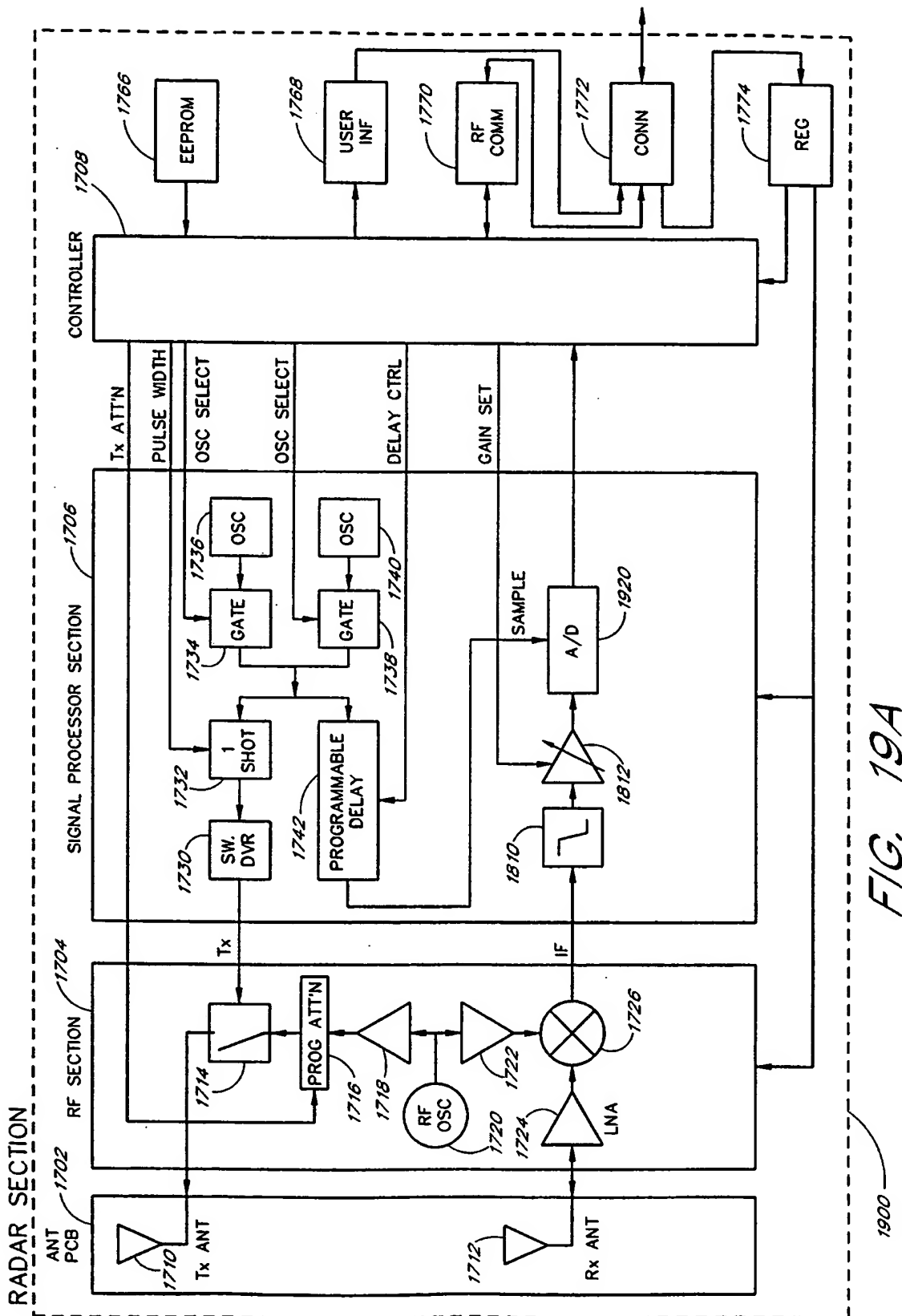
FIG. 15G

FIG. 16









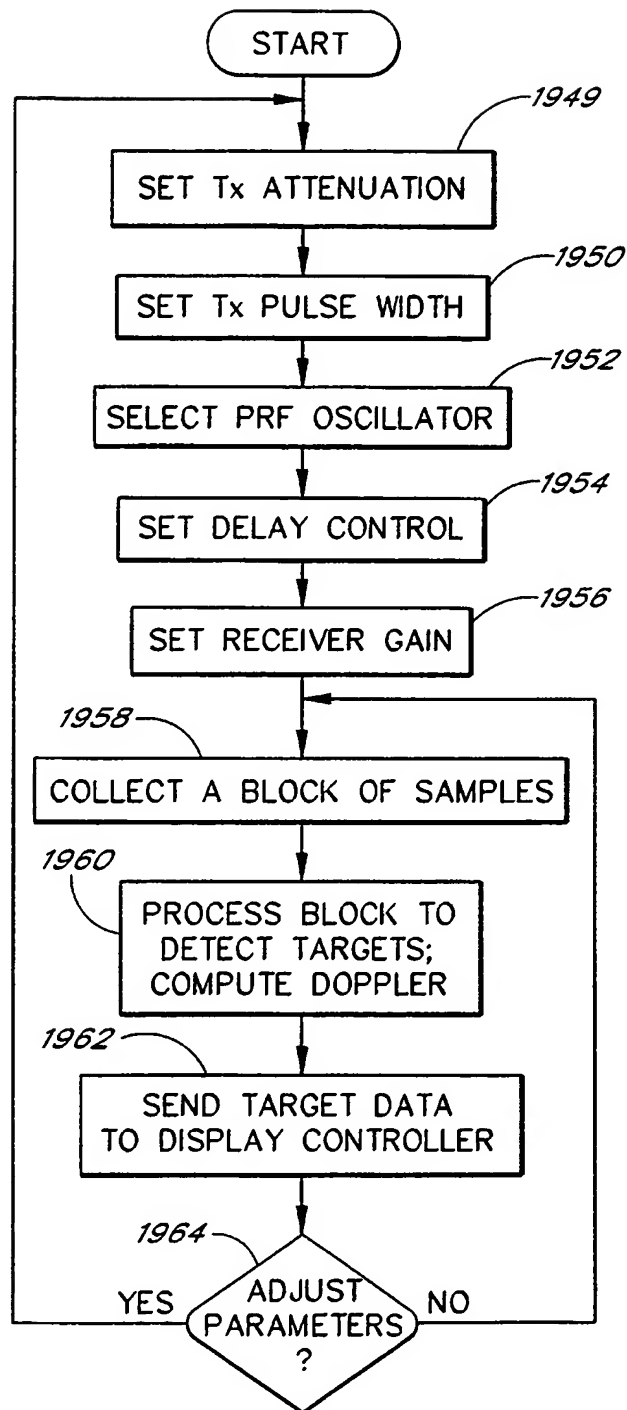


FIG. 19B

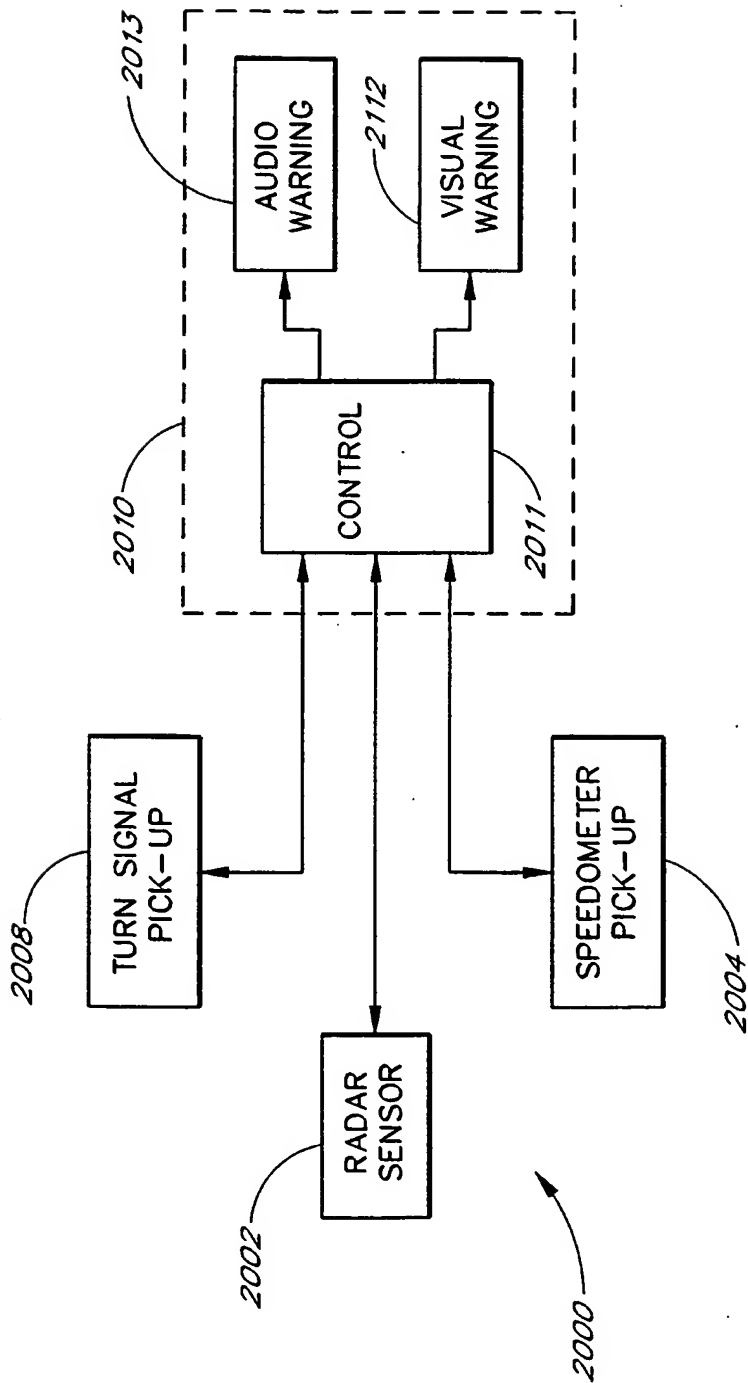


FIG. 20



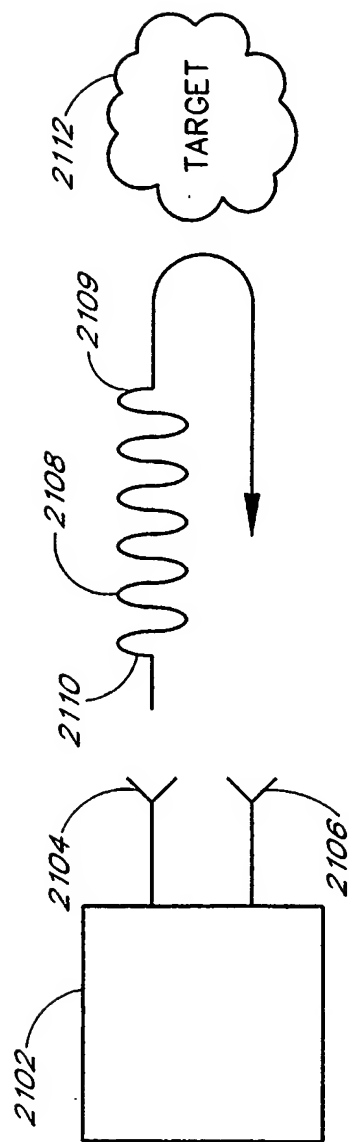
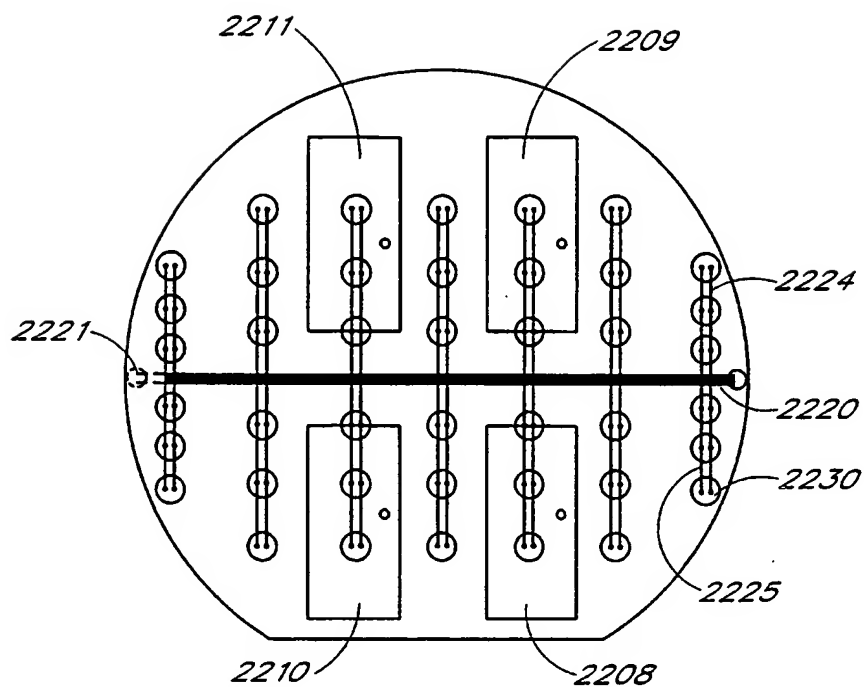
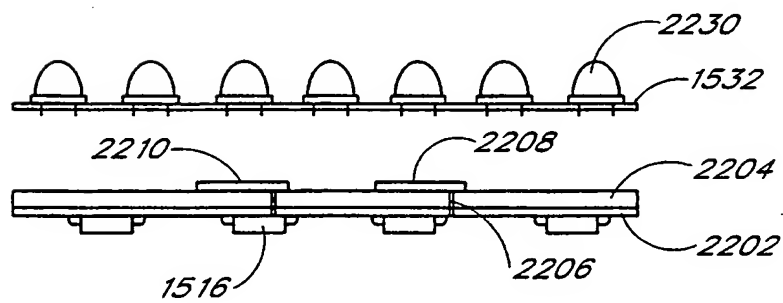


FIG. 21

*FIG. 22A**FIG. 22B*

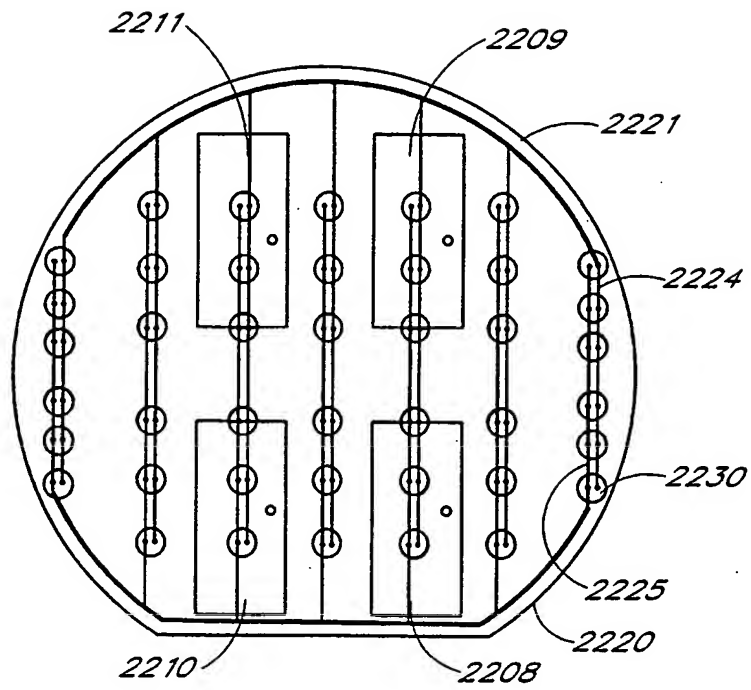


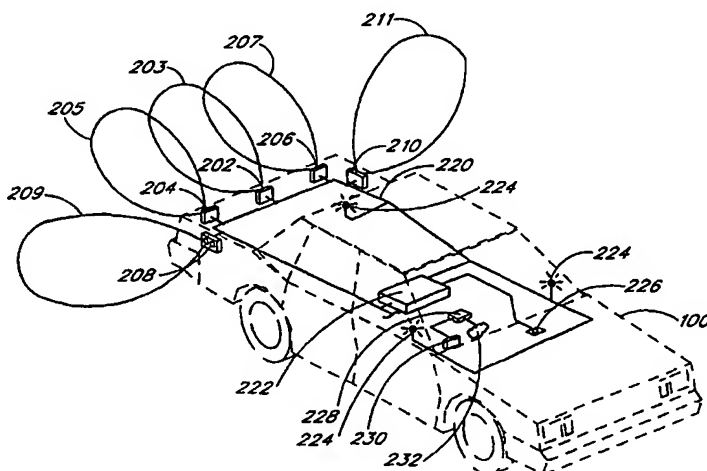
FIG. 22C



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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			(43) International Publication Date: 26 August 1999 (26.08.99)
(21) International Application Number: PCT/US99/03605		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 19 February 1999 (19.02.99)		Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(30) Priority Data: 60/075,238 20 February 1998 (20.02.98) US 09/027,996 23 February 1998 (23.02.98) US 09/106,238 29 June 1998 (29.06.98) US 09/169,679 9 October 1998 (09.10.98) US			
(71) Applicant: AMERIGON, INC. [US/US]; 5462 Irwindale Avenue, Irwindale, CA 91706-2058 (US).			
(72) Inventors: BELL, David, A.; 1819 N. Grand Oaks Avenue, Altadena, CA 91001 (US). LI, Jimmy, Moon, Kan; 345 North Norumbega, Monrovia, CA 91016 (US). DELACUEVA, Jess; 1514 California Avenue, West Covina, CA 91790 (US). TAUR, Roger; 1350 Ala Moana Boulevard #3107, Honolulu, HI 96814 (US). LEE, Kelvin, Chi; 948 S. Heritage Drive, West Covina, CA 91791 (US).		(88) Date of publication of the international search report: 4 May 2000 (04.05.00)	
(74) Agent: NATAUPSKY, Steven, J.; Knobbe, Martens, Olson & Bear, 16th floor, 620 Newport Center Drive, Newport Beach, CA 92660-8016 (US).			

(54) Title: HIGH PERFORMANCE VEHICLE RADAR SYSTEM



## (57) Abstract

A radar system is described for use in vehicular applications. The radar system is particularly suited to backup warning systems and lane-change warning systems. The radar minimizes many of the problems found in the prior art by providing programmable delays and programmable gain. The radar uses a range search algorithm to detect and sort targets at various ranges within the field of view of the radar. Each target range corresponds to a particular delay and gain setting. The radar searches for targets at the various ranges by running a target search algorithm. For each target range, the search algorithm causes the proper time delay and gain setting. Targets within the selected range are detected and catalogued. Speed of the targets is obtained through Doppler processing. A display is used to warn the driver of the vehicle of the presence of targets at the various ranges. The warning may be visual and/or audible. When used in a lane-change system, issuance of an audible warning is based on the speed of the vehicle.

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 99/03605

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G01S13/93 G01S13/88 B60Q1/48

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01S B60Q B60R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 98 00728 A (FORD MOTOR CO ; FORD WERKE AG (DE); FORD FRANCE (FR); FORD MOTOR CO) 8 January 1998 (1998-01-08)  page 7, line 22 -page 12, line 8; figures 1-10  ---	1-28, 40, 47-54, 58, 59, 86-120, 138-145, 150-163
Y	US 3 934 252 A (ROSS GERALD F ET AL) 20 January 1976 (1976-01-20)  column 3, line 34 -column 6, line 40; figure 1  ---  -/--	1-28, 47-54, 86-120, 138-145, 150-163

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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International Application No  
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2	Y US 4 673 937 A (DAVIS JOHN W) 16 June 1987 (1987-06-16)  column 3, line 66 -column 8, line 10; figures 1,2  ---	2-4,6,7, 18,21, 22, 25-28, 62, 86-89, 91,92, 101,109, 112,142, 144,155, 159-162
2	Y EP 0 817 152 A (SUN MICROSYSTEMS INC) 7 January 1998 (1998-01-07)  column 6, line 27 -column 7, line 23; figures 1,2  ---	12-14, 19,20, 22,47, 97-100, 110,111, 113,143, 153,154
2	Y EP 0 657 857 A (MAZDA MOTOR) 14 June 1995 (1995-06-14) abstract figure 1  ---	23
2	Y EP 0 412 719 A (LUCAS IND PLC) 13 February 1991 (1991-02-13) abstract figures 1-3  ---	24
2	Y US 5 682 136 A (DEL SIGNORE MAURO) 28 October 1997 (1997-10-28)  column 2, line 48 -column 3, line 30; figures 1-3  ---	44,54, 97,98, 150
2	Y US 5 446 470 A (AVIGNON BRUNO ET AL) 29 August 1995 (1995-08-29) abstract figures 2-4  ---	157,163
15	Y WO 97 32357 A (BOSCH GMBH ROBERT ;PFIZENMAIER HEINZ (DE); PETRY HANS PETER (DE)) 4 September 1997 (1997-09-04) page 9, line 9 -page 13, line 19; figures 6-8  ---  -/--	35-46, 57-72, 79-85
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International Application No  
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13 Y	EP 0 709 254 A (PEUGEOT ;CITROEN SA (FR)) 1 May 1996 (1996-05-01)  column 3, line 28 -column 3, line 56 column 6, line 41 -column 11, line 12; figures 1,6-8  ---	35-46, 57-72, 79-85
15 A	US 5 313 213 A (NEUMANN FRANK ET AL) 17 May 1994 (1994-05-17) Y column 2, line 66 -column 3, line 44; figure 2  ---	35,36, 57,79 83
2 A	US 3 794 997 A (NISHIBU M ET AL) 26 February 1974 (1974-02-26) column 4, line 28 -column 5, line 10; figures 7,9,13,14  ---	35,36, 57,79
13 A	WO 97 17232 A (VEHICLE ENHANCEMENT SYSTEMS IN ;LESESKY ALAN C (US); WEANT BOBBY R) 15 May 1997 (1997-05-15) page 6, line 22 -page 7, line 8  ---	35,36, 57,79
2 A	US 3 683 379 A (SADDLER IVAN R ET AL) 8 August 1972 (1972-08-08) column 2, line 23 -column 4, line 42; figures 1,2  ---	35,36, 57,79
15 A	US 5 598 171 A (COLE CARROLL R) 28 January 1997 (1997-01-28) abstract figures 1-3  -----	35,36, 57,79



# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 99/03605

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:  
35-46, 57-72, 79-85
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☒ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-28,47-56,86-120,138-145,150-163

An automotive radar capable of tracking and discriminating at least two Doppler shifted targets

2. Claims: 29-34

An intelligent display for providing information to the driver of a vehicle

3. Claims: 35-46,57-72,79-85

An integrated vehicle light source and radar sensor

4. Claims: 73-78

An audible warning device

5. Claims: 121-137,164-179

A lane-change aid system and a method for warning a driver when changing lane

6. Claims: 146-149

An array of light sources and a method for transmitting light energy

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/03605

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Information on patent family members

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